PERIPHYTON COMMUNITIES AS BIOLOGICAL POLISHING AGENTS IN MINE WASTE WATERS AND THE PRECIPITATION PROCESS IN TAILINGS

FINAL REPORT

by

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EXECUTIVE SUMMARY

Ecological Engineering as a decommissioning technology for acid-generating waste material from base metal mine sites is being developed on a site in northern Ontario. A zinc/copper concentrator operated **65** km northeast of Ear Falls for 10 years, producing about 760,000 short tons of tailings, covering 20 ha, and containing 41 % pyrite and **4** % pyrrhotite. The tailings are situated above a lake which has acidified during the life of the mine.

Since 1986 the site has been investigated intensively. This report represents the last detailed investigation of the hydrology and geochemistry, concentrating on the oxidation and iron precipitation rates which occur in the tailings mass. These rates define the rate at which the contaminants are released. The released contaminants entering the acidified lake are removed in this Ecological Engineered system mainly by different groups of attached algae. A literature review was carried out to provide a technical framework for biological removal processes taking place on the site.

Water samples collected from piezometers in 1990 were used to confirm that several precipitation processes could take place in the tailings mass or in the surface water receiving AMD seepage. **All** piezometer samples show super-saturation with respect to several iron minerals, including ferric hydroxides, aoethite, hematite, lepidocrocite, and maanetite, which may be precipitated. Super-saturation with respect to jarosite is shown only by samples from 2 piezometers and Mill Pond.

Samples from piezometers M4 and M10 (and from Mill Pond and Boomerang Landing) show super-saturation with respect to several aluminum minerals, including alunite, boehmite, diaspore, gibbsite, and several clay minerals.

Samples from piezometers M7B, M10, M25, M30, M47, M55, Mill Pond, and Dave's Dam show super-saturation with respect to quartz; those from M7B, M10, and M47 also show super-saturation with respect to gypsum.

Revised sulphide-oxidation rates for the South Bay tailings range from 0.0001 to 0.0427 $mol.kg^{-1}.yr^{-1}$ (overall average 0.0033 $mol.kg^{-1}.yr^{-1}$). Revised Fe-precipitation rates range from 0.000009 to 0.001135 $mol.kg^{-1}.yr^{-1}$ (overall average 0.00025 $mol.kg^{-1}.yr^{-1}$).

The literature review on periphytic algae indicated that algal growth rate data in acidic metal rich waters are scarce. However, the tolerance mechanisms of periphytic algal groups which facilitate growth and metal removal from the water were evident. Extracellular carbon in the form of sheaths or jelly is produced in response to metal and acid stress by the algal population. Extracelluar carbon production is not only related to metal and acid stress, but also to low nutrients (**P** and N) in the water or plants.

It was concluded that periphytic algae, given their biological polishing characteristics, will indeed prove to be an important contaminant removal process within the Ecological Engineering technology. Research is required to define the conditions which facilitate growth of periphytic algae, and which of the contaminant removal processes (biosieving, uptake, ad/absorption) is the main contaminant removal process. With this information, predictions on the contaminant removal capacity of the system can be made. With the contaminant release rates determined here, the overall effectiveness of biological polishing as a process can be determined.

RESUME

Le génie Bcologique, en tant que technologie de décommissionnement pour les matériaux de déchet générateurs d'acide à partir des chantiers des mines de métaux de base est en train d'être mis au point dans un chantier du Nord de l'Ontario. Un concentrateur de zinc/cuivre a fonctionné à 65 km au nord-est de Ear Falls, pendant 10 ans, produisant environ 760 000 tonnes courtes de résidus, couvrant 20 ha, et contenant 41% de pyrite et 4% de pyrrhotite. Les résidus sont situés au dessus d'un lac qui s'est acidifié pendant la durée de vie de la mine.

Depuis 1986, le chantier a fait l'objet d'une enquête intensive. Le present rapport représente la dernihre enquête détaillé sur l'hydrologie et la géochimie, en se concentrant sur les vitesses d'oxydation et de précipitation du fer qui surviennent dans la masse des résidus. Ces vitesses définissent la vitesse à laquelle les contaminants sont libérés. Les contaminants libérés entrant dans le lac acidifié sont amenés dans ce systhme de construction Bcologique, principalement par différents groupes d'algues attachées. Une Btude de documentation a été effectuée afin de fournir un cadre technique aux procédés d'enlhvement biologique ayant lieu sur le chantier.

Les Bchantillons d'eau prélevés des pihzomhtres en 1990 ont été utilisés afin de confirmer que plusieurs procédés de précipitation pourraient avoir lieu dans la masse des résidus ou dans l'eau de surface recevant le suintement AMD. Tous les Bchantillons des pihzomhtres montrent une super-saturation en ce qui concerne plusieurs minerais de fer, incluant les hydroxydes ferriques, la goethite, l'hématite, la lépidocrocite, et la magnétite, qui peuvent être précipités. La super-saturation, en ce qui concerne la jarosite, n'est montrée que par des Bchantillons à partir de 2 pihzomhtres et Mill Pond.

Les Bchantillons à partir des pièzomètres M4 et M10 (et à partir de Mill Pond et Boomerang Landing) montrent une super-saturation en ce qui concerne plusieurs minéraux d'aluminium, incluant l'alunite, la boehmite, la diaspore, la gibbsite, et plusieurs minéraux argileux.

Les Bchantillons à partir des pihzomhtres M7B, M10, M25, M30, M47, M55, Mill Pond et Dave's Dam montrent une super-saturation en ce qui concerne le quartz; ceux a partir de M7B, M10 et M47 montrent aussi une super-saturation en ce qui concerne le gypse.

Les vitesses révisées d'oxydation sulfurée pour les résidus de South Bay vont de 0,0001 a 0,0427 $mol.kg^{-1}.yr^{-1}$. (moyenne globale de 0,0033 $mol.kg^{-1}.yr^{-1}$). Les vitesses de precipitation révisées du Fe vont de 0,000009 à 0,001135 $mol.kg^{-1}.yr^{-1}$ (moyenne globale de 0,00025 $mol.kg^{-1}.yr^{-1}$).

L'étude des documents sur les algues périphytiques a indiqué que les données sur la vitesse de croissance des algues dans les eaux riches en métaux acidiques sont rares. Cependant, les mécanismes de tolerance des groupes d'algues périphytiques qui

facilitent la croissance et l'enlèvement des métaux à partir de l'eau étaient évidents. Le carbone extracellulaire, sous forme de gaines ou de gelée est produit par la population des algues en reaction au stress métallique et acide. La production de carbone extracellulaire est liée, non seulement au stress métallique et acide, mais aussi aux éléments nutritifs bas (P et N) se trouvant dans l'eau ou les plantes.

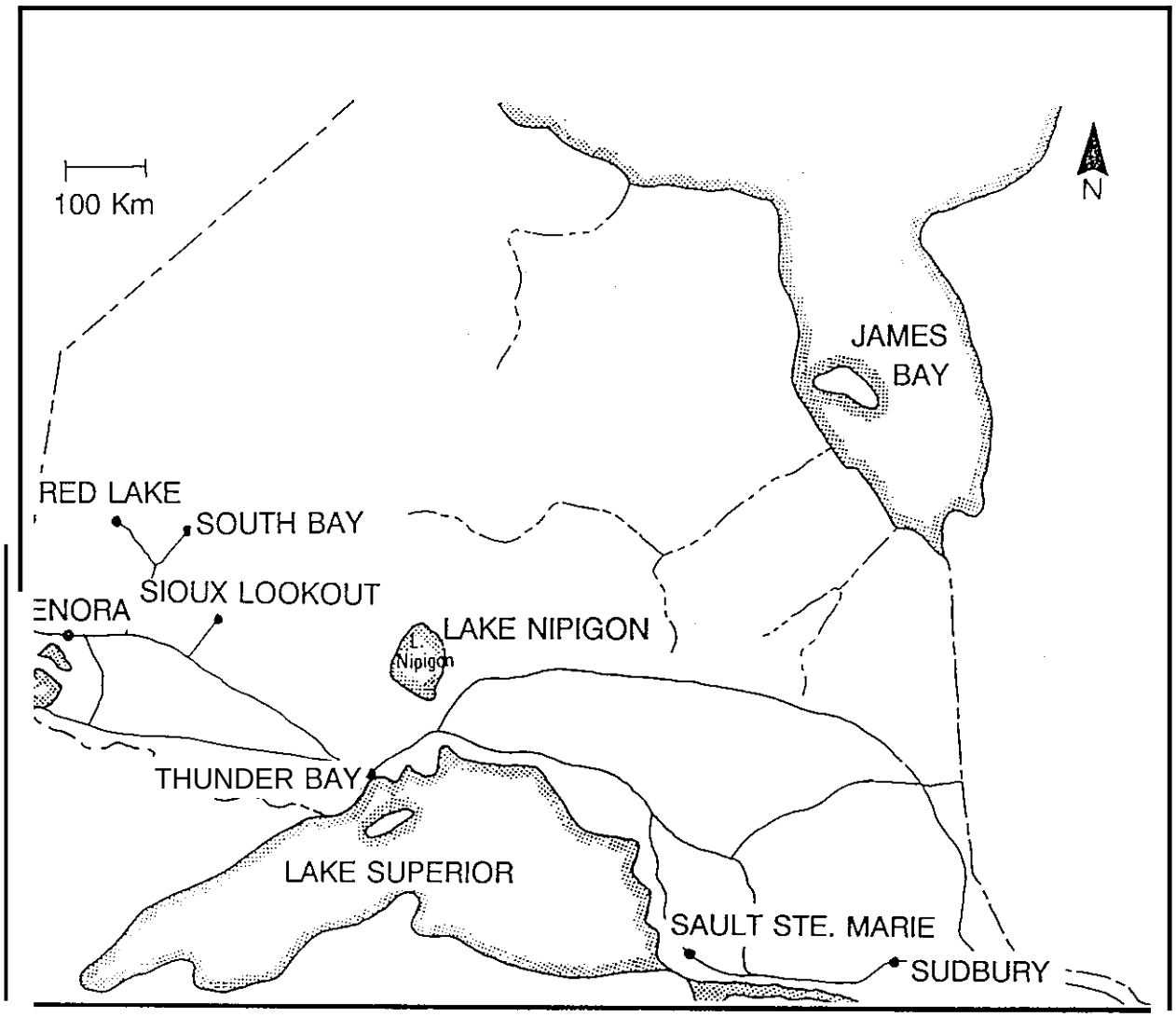
Il a été conclu que les algues périphytiques, étant donné leurs caractéristiques de polissage biologiques, s'avéreront vraiment être un procédé important d'enlbvement des contaminants dans la technologie de génie Bcologique. La recherche est nécessaire afin de définir les conditions qui facilitent la croissance des algues périphytiques, et de determiner celui des procédés d'enlbvement des contaminants (biotamisage, montée, ad/absorption) qui est le principal procédé d'enlèvement des contaminants. Avec ces informations, on peut prédire la capacité d'enlbvement des contaminants du systbme. Les vitesses de liberation des contaminants étant déterminées ici, on peut determiner l'efficacité globale du polissage biologique en tant que procédé.

1.0 INTRODUCTION

Implementation of Ecological Engineering as a decommissioning technology for acid-generating, base metal mining wastes has been carried out on a site in northern Ontario. The site is located 65 km northeast of Ear Falls (Map 1.1). A zinc/copper concentrator was operated there from 1971 to 1981. The 760,000 short tons of tailings cover an area of about 20 ha, containing about 41% pyrite and 4% pyrrhotite.

Since 1986 the site has been investigated intensively to determine those measures which are required to implement Ecological Engineering technology (Kalin and Smith 1988; Kalin 1989a; Kalin et al. 1989b; Kalin et al. 1989c; Kalin 1990a,b). One of the key factors which will determine the effectiveness by which biological measures remove contaminant loadings is the rate of contaminant release from the tailings and the growth rates of contaminant removal systems, ie. the periphytic algae.

Rates of sulphide oxidation and iron precipitation were estimated through: analysis of water collected from piezometers since 1986, water level monitoring, evaluation of climatological records, and measurement of hydrological and physical characteristics of the tailings mass. Sulphide oxidation and iron precipitation rates are related to the annual recharge at the tailings site. The annual recharge is a function of precipitation (snow and rain). Using geochemical analysis of piezometer water and the estimated amount of annual recharge, sulphide oxidation rates ranged from 0.0001 to 0.0135 $mol.kg^{-1}.yr^{-1}$,

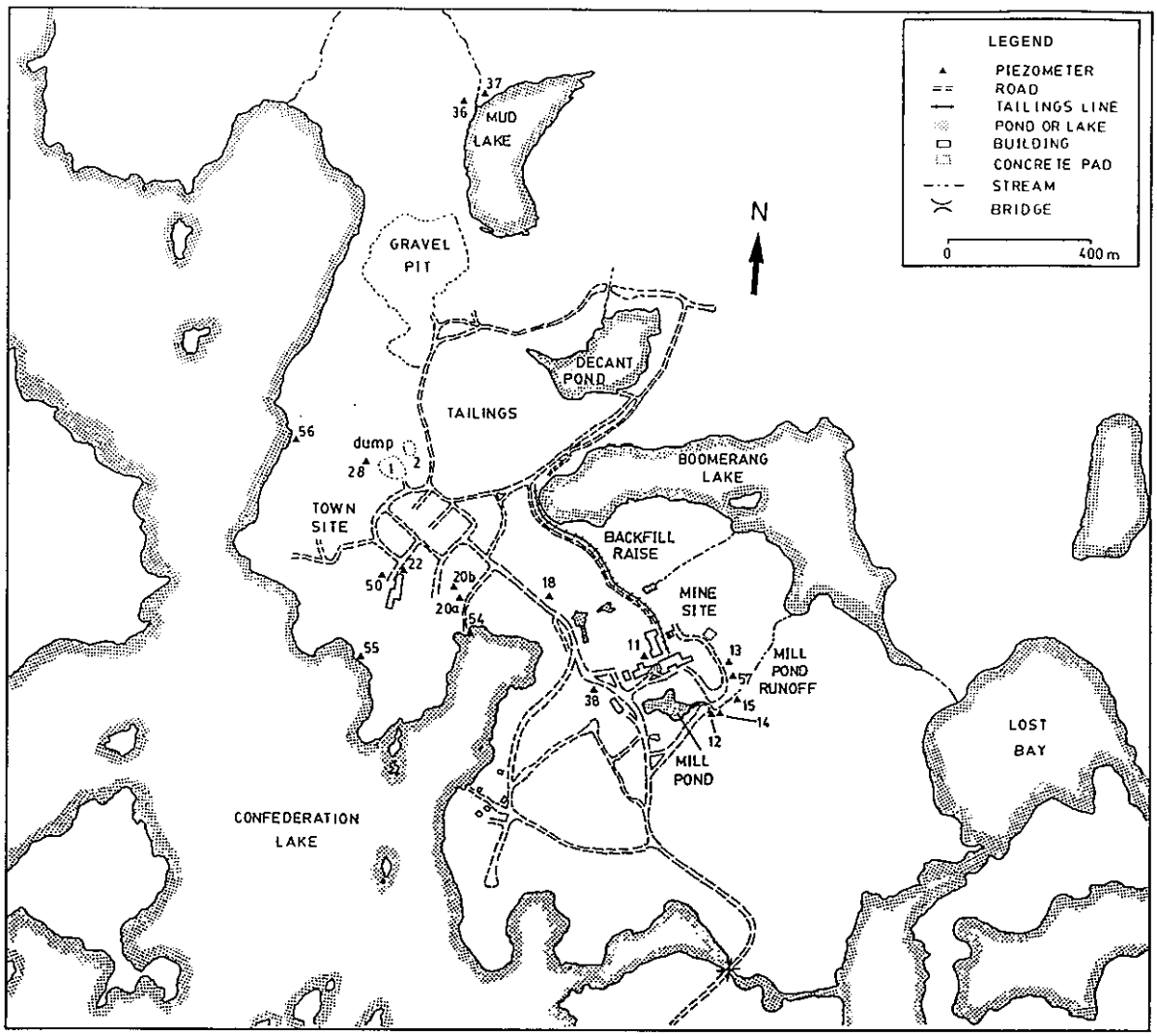


MAP 1.1: South Bay Location Map

whereas the iron precipitation rates in the tailings were estimated to be even larger, ranging from 0.00001 to 0.00155 $mol.kg^{-1}.yr^{-1}$ (Kalin et al. 1990). These large ranges required "fine tuning" with climatic records. A comparison of climate data from the two nearest weather stations had to be carried out along with a preliminary investigation of *in situ* mineral precipitation in the tailings mass. Initial data predicted that mineral precipitation would be significant.

Biological polishing, utilizing two algal groups, was used in the Ecological Engineering decommissioning concept to control zinc concentration in those water bodies affected by the tailings (Boomerang lake, Decant Pond, Mill pond, Polishing pond/ditch). The location of these water bodies in relation to the tailings is shown in Map 1.2. A literature search was required to provide a technical framework, describing the viability of filamentous algae, their growth and uptake rates as metal removal systems. The literature review, together with the data obtained to date on indigenous algal populations, will form the foundation of further technology development, leading to the substantiation of the long-term viability of biological polishing as an Ecological Engineering process.

The literature reviewed describes the role of periphytic algae in removing soluble metals from waste water, and relates that to Biological Polishing at the site in Section 2. The fine tuning of the *in situ* rates of iron precipitation and oxidation along with descriptions of precipitation products in section 3.



MAP 1.2: South Bay Mine Site Map

2.0 PERIPHYTIC ALGAE AS BIOLOGICAL POLISHING AGENTS

Algae are one important component of natural cleansing processes in surface water. Several key periphytic algal complexes have been identified by Boojum Research Limited being present in different types of mine waste waters. These algae serve as polishing agents which through ad/absorption concentrate metals several orders of magnitude higher than the surrounding waste water.

Filamentous macroalgae grow in several areas in and around mine sites. Blue-green algae, including the genera Lyngbya, *Oscillatoria,* and *Phormidium* occur in alkaline to neutral waste ponds. Green algae in the order Ulotrichales, including *Ulothrix, Microspora,* and *Klebshomidium,* occur in seepages and acidic ponds and ditches. These algae have been found to grow profusely under certain conditions in the waste water. However, these conditions, which promote prolific growth of the populations are unknown.

Algal populations at the South Bay site have been studied in detail previously (Kalin et al. 1989a). The filamentous algal populations described as polishing agents were present in 1990, when the site was visited during this investigation. Algae from South Bay were put into culture to determine factors which control growth and polishing.

2.1. Periphyton Field Collections and Identifications

Periphyton (algal) samples from various locations within the South Bay mine site (Map 1.2) were collected in waste waters ranging in pH from 4 to 6. Samples were processed for identification, culture and elemental analysis by ICP.

In many cases, it was not possible to identify algal samples further than genus, as algal taxonomy of many of the chlorophytes is based on morphology of reproductive structures, which may or may not be present. It is also possible that algae will only grow vegetatively, which is frequently the case in waste water.

The dominant algae with polishing capacity are shown in Tables 2.1 for Mill pond , in Table 2.2 for Boomerang Lake and for the Polishing pond/ditch in Table 2.3 (Map 1.2). These included multicellular Ulothrix and the mat-forming, blue-green cyanophyte, Oscillatoria. Unicellular algae associated with the multicellular forms included Euglena mutabilis, Chlamydomonas spp., Ankistrodesmus sp. and Sphaerellopsis cylindrica.

Boomerang Lake, the lake which had acidified during mine operations to Ph 3.5, contained a number of minor dinoflagellates, desmids and diatoms. Interestingly, at the time of collection, there was a massive bloom of Stichococcus sp., a very small, unicellular chlorophyte, which turned the entire lake a fluorescent green. Boomerang

TABLE 2.1: ALGAL TAXA REPORTED FROM MILL POND (October 13,1990)

Division	Genus	Growth Substrate
Chlorophyta		
	Ankistrodesmus spp.	leaves, branches, mats
	Chlamydomonas sp.	leaves and branches
	Euglena sp.	leaves and branches
	Euglena mutabilis	algal mat
	Sphaerellopsis cylindrica	algal mat
	Ulothrix spp.	dominant, leaves, branches, mat
Cyanophyta		
	Oscillatoria spp.	leaves and branches
Chrysophyta		
	small chrysophyte	very common, leaves, branches, mat

Lake also contained a number of filamentous algal communities on log booms and submerged brush (used for enhancing algal growth: Table 2.2). These included the "black" green alga, Microspora sp., the ever present Ulothrix spp., and perhaps Zygogonium sp.

Boomerang Lake also contained "jelly" like algal mats on submerged brush, dominated by Achnanthes spp. In the past, these algae have been very common, but on this collection trip, they were a minor component of the algal flora (Table 2.2). This diatom community has been shown to be a major biological polishing agent (see Kalin et al. 1989a).

A third area surveyed was the polishing pond and ditch. These areas contained a number of small communities, dominated by *Ulothrix* and Euglena *mutabilis*, although

Chlamydomonas, Oscillatoria tenuis, and several diatom species were also present (Table 2.3).

It was decided to put Ulothrix and some of the cyanophytes into culture. These cultures with others previously collected and cultured by Boojum Research, constitute a diverse genetic bank biological polishers from mine sites across Canada (Table 2.4).

TABLE 2.2: ALGAL TAXA REPORTED FROM BOOMERANG LAKE (October **13,1990)**

Division	Genus	Growth Substrate
Chlorophyta		
	Carteria sp.	logs and branches
	Chlamydomonas spp.	phytoplankton sample
	Chlorella spp.	epiphytic on moss
	Cosmarium sp.	log booms, branches, and **moss**
	Euglena spp.	log booms, branches, and moss
	Gloecoccus spp.	log booms, branches, and moss
	Microspora sp.	dominant alga on some logs and branches
	Netrium sp.	log booms, branches, and moss
	Sphaerellopsis cylindrica	log booms, branches, plankton, moss
	Staurastrum pachyrhychum	log booms an branches
	Stichococcus sp.	dominant in plankton samples
	Ulothrix spp.	dominant on moss and some logs, some with Fe
	Zygogonium sp.	dominant on **moss,** may be Microspora
Cyanophyta		
	Chroococcus spp.	log booms and branches
Dinophyta		
	Glenoodinium sp.	plankton, log booms, and branches
	Peridinium sp.	epiphytic on moss
	Peridinium inconspicuum	epiphytic on moss
Bacillariophyta		
	Eunotia *fallax*	log booms and branches
	Eunotia sp.	log booms, branches, and moss
	Melosira sp.	log booms and branches
	Pinnularia spp.	log booms, branches, and **moss**
	Rhodopalodia gibba	epiphytic on moss
	Tabellaria flocculosa	epiphytic on moss
	small chrysophytes	epiphytic on moss
	small unicells and flagellates	l o booms, branches, and moss

TABLE 2.3 ALGAL TAXA IN THE POLISHING POND AND DITCHES (October 24, 1990)

Division	Genus	Growth Substrate
Chlorophyta		
	Chlamydomonas spp.	seepages
	Cosmarium sp.	seepages
	Euglena sp.	pond mats
	Euglena *mutabilis*	ditch, ditch mats
	Netrium sp.	seepages
	Microspora sp.	seepages
	Mougeotia sp.	seepages
	Sphaerellopsis cylindrica	pond mats, ditch mats
	Staurastrum sp.	pond mats
	Temnogametum sp.	seepages
	Ulothrix sp.	dominant pond mats, seepages, ditch mats
Cyanophyta		
	Anabaena sp.	seepages
	Oscillatoria sp.	dominant in pond mats,
	Oscillatoria *tenuis*	pond mats
Bacillariophyta		
	Achnanthes sp.	dominant in seepages
	Eunotia spp.	ditch mats
	Navicula sp.	seepages, pond mats
	Nitzschia sp.	seepages, pond mats
	Pinnularia spp.	seepages, pond mats, ditch mats

TABLE 2.4: SOURCES OF ULOTHRIX SP. CULTURES

CODE	COLLECTION SITE	MEDIUM
BR-003	South Bay, Mill pond	BBM (pH 6.8)
BR-008	Levack, seepage	BBM (ph 6.8)
BR-012	Falconbridge, seepage	BBM (ph 4)
BR-013	South Bay, Decant Pond	BBM (pH 6.8)
BR-014	Kam Kotia (KJ 8)	BBM (pH 4)
BR-016	Pamour - Timmins	BBM (pH 6.8)
BR-017	Levack, seepage (site X)	BBM (pH 4)
BR-019	Levack, seepage (site VII)	BBM (pH 6.8)
BR-021	Olive Lake	BBM (pH 6.8)
BR-023	Onaping High Ni Pond	BBM (pH 4)
BR-044	Nanisivik (station 159.6)	BBM (Ph 6.8)
BR-048	Buchans	BBM (pH 6.8)
BR-049	Selminco, seepage	BBM (pH 6.8)
BR-050	Selbaie, I ditch seepage	BBM (pH 4)

2.2. Biological Polishing with Periphyton

Initial collections of algae and aquatic macrophytes from a variety of habitats at the South Bay mine site revealed a variety of responses to elevated metal concentrations. In the Decant pond (Map 1.2), cyanophytes predominated the periphytic communities. These cyanobacteria contained as much as 6.9% zinc on a dry weight basis. *Ulothrix* populations in the mill pond, contained up to 2.9% zinc. Analyses also showed that the plants in Mill pond contained as much as 29% iron, and 3.2% aluminum. Even the aquatic macrophytes in the polishing pond contained elevated concentrations *of* heavy metals. *Potemogeton* contained 0.2% zinc, 3.8% iron, and 2.8% aluminum.

TABLE 2.5: Biological Polishing of metals by S. Bay algae in 1990.
(% of metals on a dry weight basis and concentration factors)

		Metal content			Concentration F.		
Algal Taxa	Date	Zn	Fe	Al	Zn	Fe	Al
Mill Pond ***Ulothrix***	25-Aug	0.1	2.9	3.2	1.7	151	2050
Mill Pond *Ulothrix*	12-Oct	2.9	28.6	1.5	41	1490	962
Mill Pond ***Ulothrix***	12-Oct	0.1	5.6	0.6	1.1	292	385
Decant P. cyanophytes	14-May	6.9	9.8	2.0	7840	7*10^4	>5*10^5
Decant P. cyanophytes	25-Aug	1.4	3.4	1.1	1590	3*10^3	>3*10^5
Polishing P. Ulothrix	14-May	**0.1**	5.0	5.8	3125	6*10^5	>1*10^6
Pol. P. *Potemogeton* old	28-Jun	0.2	3.8	2.8	6250	5*10^5	>7^5
Pol. P. Potemogeton yng	12-Oct	0.2	1.3	1.5	6250	2*10^3	>4*10^5
Mill pond water mg/L	12-Oct	175	48	3.9			
Decant Pond mg/L	12-Oct	2.2	3.3	0.01			
Polishing Pond mg/L	12-Oct	0.08	0.02	**0.01**			

It is interesting to note that the concentration factors (i.e. the concentration of metal in algae on a fresh weight basis/concentration in water), seemed to be high in areas with low concentrations, and low in areas with high concentrations. This is not unexpected if one assumes that the concentration factors are biological in origin, and not merely chemical or physical adsorption.

2.3. Literature Review

Based on the data presented in the previous section, algae appear to be an obvious choice for biological polishing, if their growth could be promoted. However, before confidence can be gained in this area, a literature search was used to define the framework in which the research should be carried out. The objective of the literature review, therefore, was to determine the background level of knowledge on periphytic macroalgae in relation to metal uptake and growth in acidic and circumneutral mine waste waters.

The material reviewed covered the time period from 1970 to 1990, with an emphasis on the more recent literature which could be expected to contain work related to acidic mine drainage. The literature review focused primarily macrophytic algae, with selected references included on microalgae. The references of the reviewed papers are given alphabetically in appendix 1. To improve readability, only a few of the better examples and more important references are quoted in the text.

Three main areas relevant to the topic were searched,

1. Metal tolerance and toxicology.
2. Metal - Algal interactions, including accumulation.
3. Acid tolerance

Macroalgae are ideal biological polishing agents in most mine waste water situations. They are also most amenable to field amplification. Knowledge about these algae, however, is scant. For the most part, the Chlorophyta (green algae) dominate the macrophytic work in fresh water, and the Phaeophyta (brown algae) dominate the work in the marine environment. In fresh water, most of the species studied, including *Ulothrix, Stigeoclonium, Klebshormidium (Hormidium), Microspora, Stichococcus*, and the marine, green, *Ulva* are all members of the same order, the Ulotrichales (Pickett-Heaps **1975).** Other groups, though, including the Zygnemetales (*Mesotaenium*) (Mangi and Schumacher **1979),** and Lemanea (Harding and Whitton 1981), a freshwater rhodophyte have been studied. Of the marine algae studied, kelps and beach wracks are more prominently featured, including *Ascophyllum, Fucus* and Laminaria, although the fouling alga, *Ectocarpus* has also used extensively as a test organism (Hall **1980, 1981).** Among the cyanobacteria, those filamentous, sheath-formers, such as Anabaena, Lyngbya, and *Oscillatoria*, and the gelatinous *Anacystis* have been occasionally cited. However, even though there seem to be consistencies in the taxonomic position of metal tolerant

macroalgae, both Whitton (1970) and Stokes (1983) caution that metal tolerance can be found in many diverse taxonomic groups.

The greatest number of papers, however, deal with the microalgae. Here Chlamydomonas, Chlorella, Euglena and the diatoms are commonly chosen for their ease of culturing. These studies deal mostly with toxicology, using algae as indicators of metal contamination, such as the work of Keeney et al. (1976).

2.3.1. Metal tolerance and toxicology

Most of the metals found in the aquatic environment are required in trace amounts as catalytic agents in normal physiological processes (Weinberg 1977). But, in elevated concentrations, these metals become toxic to most plant and animal life. Some plants, including some of the algae, have become tolerant to elevated concentrations of these metals. The tolerance level, or inversely, the toxicity of the metals, is dependent on several chemical and biological factors.

Heavy metal concentrations, which under some circumstances are tolerated, can become toxic under other conditions. Conditions which affect the toxicology of heavy metals include chemical speciation, and the influence of other ions such as H^{+}, Ca^{+2} (Hargreaves and Whitton 1976; Sunda and Guillard 1976; Paterson et al. 1984; Campbell and Stokes 1985).

Attached, or periphytic algae have been shown in a number of studies to grow in streams and ponds which contained mine waste water and consequently, elevated concentrations of metals (Bennett 1969; Whitton 1970; Hargreaves et al. 1975; Say and Whitton 1980; Foster 1982; Kalin et al. 1989). These studies and others have lead to several major reviews dealing with algal heavy metal tolerance (Whitton 1970; Rai et al. 1981; Stokes 1983; Reed and Gadd 1990).

2.3.2. Metal-Algal interactions

Most of the literature uncovered to date, which is concerned with metal-algae interactions, falls into three groups. The first group describe the ability of some algae to tolerate elevated metal levels (Harding and Whitton 1976; Bently-Mowat and Reid 1977; Butler et al. 1980; Fisher 1981; Bariaud and Mestre 1984, 1985; Klerks 1987; Twiss 1990), and the related ability to accumulate these metals at concentration ranges 100-1000 fold over ambient (Coleman et al. 1971; Foster 1976; Sakaguchi et al. 1979; Hasset et al. 1980; Harding and Whitton 1981; Foster 1982; Stary and Kratzer 1982).

The second thrust is toward classical toxicology testing using algae as test organisms (Morel et al. 1978; Keeney et al. 1976; Norberg and Molin 1983; Rachlin et al. 1984). These papers deal primarily with phytoplankton.

The third area deals with how these accumulations are made possible. Much of the literature deals with the effect of extracellular substances on metal sequestration. Papers on metal-ligands, siderophores, extracellular polysaccharides are common (Foster 1977; Swallow et al. 1978; Mangi and Schumacher 1979; McKnight and Morel 1979, 1980; Van den berg et al. 1979; Hart 1981; Fisher and Fabris 1982; Strong et al. 1982; Sueur et al. 1982; Jardim and Pearson 1984; Seritti et al. 1986; Gekeler et al. 1988).

Cell walls are also charged surfaces, which can attract and bind metals (Cain and Allen 1980; Crist et al. 1981; Stary and Kratzer 1984; Xue et al. 1988). Thus, these extracellular molecules, and cell wall surfaces will bind metals without the assistance of the living cell (Tsezos and Bell 1989).

Active sequestration of metals seems to be related to the production of metal-proteins (metallothioneins) and polyphosphate bodies within the cell or vacuolar storage (McLean et al 1972; Rana and Kumar 1974; Jensen et al. 1982; Piccinni et al 1985; Heuillet et al. 1986; Heuillet et al. 1988a,b).

A few of the papers deal with the physiology of uptake (Gutnecht 1963,1965; Skipnes et al. 1975; Gnassia-Barelli and Hadstedt-Romeo 1982; Harrison et al. 1986). Others concentrate on the effects of excessive concentrations of metals on other physiological processes such as photosynthesis and respiration (De Filippis and Pallaghy 1976; Overnell 1976; De Filippis et al. 1978; Fisher et al. 1981).

While almost all of the studies found indicated that extracellular carbohydrates, siderophores, ligands, etc. were linked to metal tolerance, almost none of them tried to link the production of these chemicals to the physiology of the algae. Periphytic algae from ombotrophic mires, oligotrophic ponds, lakes, and streams must deal with extremely low nutrient levels. The result is that photosynthetic production by these algae cannot be incorporated into proteins, which require nitrogen. The excess carbon produced is generally exported (Munster and Chróst 1990). Therefore, in nutrient poor environments, the production of extracellular carbon compounds, such as mucopolysaccharides, carbohydrates, glycolate, etc. is fundamentally linked to the physiological status of the plant (Harrison et al. 1977; Simões Gonçalves et al. 1988).

Phosphate uptake, polyphosphate bodies, and metals have been linked in several studies (Rana and Kumar 1974; Jensen et al. 1982). Polyphosphate bodies are formed as storage products when phosphate is taken up to excess. Uptake of phosphate without nitrogen, will also produce extracellular carbon.

2.3.3. Effects of acidity on algal growth/polishing

Another aspect of the physiology which has received scant attention is the ability of algae to photosynthesize under acidic conditions. The studies addressing pH consider *5* to be acidic. Many of the algae growing in waste rock seeps at mine sites, and in acid mine

drainage, can photosynthesize and grow at pHs substantially under 5. For example, Euglena *mutabilis* can be found in acid pools at pHs below 2 (Olaveson 1984). At this pH almost all, if not all, carbon dioxide has been removed from water. Photosynthetic carbon fixation then becomes limiting. Organic carbon may be the only source available. Until recently, however, uptake of organic carbon has only been shown for unicellular algae (Olaveson 1984 for review). Although not in an acidic environment, Markager and Sand-Jensen (1990) have shown the uptake and use of organic carbon by the macrophytic green alga, *Ulva*. Organic carbon allows the plant to keep its chloroplasts in dim light, and supplements the photosynthetic uptake of inorganic carbon. Cyanobacteria have also been shown to utilize organic carbon (Guest and Fay 1976).

Under acidic conditions, nutrient availability, other than carbon, also decreases (Tucker et al. 1987). Mineralization, the break down of organic matter, including fresh residue, supplies much of the N and P needed by plants (Kamprath and Foy 1971). Since acidity slows microbial regeneration of the nutrients, they are less available.

Growth rates of macroalgae in mine waste water have been studied (Hargreaves and Whitton 1976; Shehata and Whitton 1981). Growth rates of the same algae in the laboratory are also not numerous (Kratz and Myers 1955; Hindak 1970; Harding and Whitton 1977; Shehata and Whitton 1981).

Measurements of biological polishing capacity and growth for the same organism are available only for the marine wrack, ***Ascophyllum*** (Seip **1979).** Data also exist for unicellular algae grown industrially in bioreactors (Matusiak et al. **1976;** Norberg and Person **1984;** Sloan et al. **1983;** Przytocka-Jusiak et al. **1984).**

Reports of biosieving, where algae remove suspended material, have not been found in the literature. Transformation of dissolved metal ions to precipitated, inorganic metallic sulphides and the geochemical implications of the transformations, though, have been studied (Mann and Fyfe **1985** a,b; Stevens et al. **1989).**

2.4. Conclusions

Many macrophytic algae seem to be able tolerate relatively high concentrations of metals, and low pHs. They can accumulate metals, and also release them back to the environment. Rates of metal accumulation and growth, however, are almost non-existent in the literature reviewed. Algae tolerate metals primarily through production of extracellular carbon which is often found in the form of mucopolysaccharides, forming protective sheaths and jellies of the cyanobacteria and diatoms. In response to metal concentrations the production of metal-ligands, siderophores, chelators which trap metals is reported, lowering toxicity of the metals. Algae can also take up metals and sequester them in vacuoles, proteins, or polyphosphate bodies. Extracellular carbon production

may be related not only to the presence of metals, but to the nutritional status of the plant. The surfaces of periphyton provide a habitat for epiphyton, where together with bacteria metals can precipitate. The algal mass ultimately is rendered anaerobic, where remineralization of metal ions into metal-sulphides can occur.

There appears to be only descriptive literature on the subject of macroalgal biopolishing of mine and other waste waters. Basic questions dealing with growth rates, limiting factors, uptake rates and feasibility for large-scale production have not been dealt with in a systematic way.

3.0 PRECIPITATE FORMATION WITHIN THE TAILINGS MASS

The hydrological and geochemical conditions of the 760,000 short tons tailings basin in South Bay containing 41% pyrite and 4% pyrrhotite have been studied in detail (Kalin et al. 1989b). This study indicates that some of the initial Fe is precipitated in the tailings pile or in the underlying sediments. The precipitate likely takes the form of iron hydroxide, Na-Jarosite, and gypsum. It is also likely that other elements such as Zn, are co-precipitated with the iron. The annual recharge of the tailings basin was calculated based on data from the closest weather stations in Ear Falls. The measurement of water level in the tailings mass has been carried out for a period of three years.

These data were used to determine sulphide-oxidation rates and iron precipitation rates in $mol.kg^{-1}.yr^{-1}$. Both rates were found to have a large range, over two orders of magnitude (eg. 0.0001 to 0.0117 $mol.kg^{-1}.yr^{-1}$ for sulphide oxidation). These rates are dependent on the thickness of the unsaturated layer within the deposit and the recharge rates of the tailings basin.

To define and verify these rates, good climate data must be available. The following section describes the calibrations necessary to utilize local government weather data. Water level readings have also been taken on a monthly basis in some 50 piezometers around the tailings mass.

The geochemistry of metal precipitates in the tailings mass is complex, yet a first approximation has been calculated based on piezometer water chemistry, weather data and water table fluctuations. To verify these rates, it was essential that samples from selected locations be collected, the precipitate location logged in relation to the water level fluctuations, and finally, its chemical form be determined analytically. The following tasks were carried out in order to verify the oxidation and precipitation rates and the composition of the precipitate.

3.1. Climate Records and Weather Analysis

This objective of the study undertaken was to determine how well the rate and timing of precipitation at the South Bay tailings site can be expected to be represented by precipitation data from the weather station at Ear Falls, *67* km southwest of the site.

The report also contains updates to the data previously analyzed (Kalin et al. 1990), covering the period from October **1989** to October **1990,** for the records of groundwater levels and subsurface temperatures **in** the tailings basin, and for precipitation and rainfall at Ear Falls, as well as field data and chemical analyses for water samples collected by Boojum Research Ltd. in October **1990.**

In addition, the report presents the results of geochemical calculations of the degrees of saturation of the 1990 water samples with respect to a number of potential precipitate minerals, and revised rates of sulphide oxidation and iron precipitation.

3.1.1. Rainfall comparisons

Currently there is no weather station at South Bay (51°08'N, 92°40'W), and precipitation records from the nearest weather station at Ear Falls (50°38'N, 93°13'W), about 68 km southwest of the site, have been used to interpret water level variations at the site.

In late 1989 it was recommended that a recording rain gauge be operated at the site, at least during the frost-free season, **so** that comparison of local data from the gauge with data from Ear Falls could reveal how well (or how poorly) the Ear Falls precipitation data actually represent rainfall at South Bay. However, it turned out that rainfall (and temperature) had been recorded on the site during the summers of 1973 to 1986, and it was therefore decided to check the available South Bay data for correlation with data from Ear Falls.

A print-out of the South Bay data was obtained from the Northwest Regional Fire Centre. The data cover the months of May to September for most of the years from 1973-1986. No data are available for South Bay for other months. The Atmospheric Environment Service (AES) of Environment Canada provided daily weather data, on disk, for the Ear

Falls station for the period from January 1971 to December 1984; daily data for the ensuing years was already on-hand. Information on monthly precipitation totals was also available for the station at Red Lake (51°04'N, 93°48'W), some 79 km WNW of the site.

The precipitation data available for the period of overlap, 1973-1986, were processed to allow a comparison of summer rainfall at South Bay with precipitation at Ear Falls and Red Lake.

3.1.2. Comparison between stations

Monthly means of precipitation for the two permanent weather stations (from AES 1951-1980 Climate Normals) are shown in Figure 3.1A (See Appendix 2 for all Figures and Tables in this section). Monthly means of precipitation for the 5-year period 1982-1986 for the two stations, and for the South Bay site, are shown in Figure 3.1 B. The two figures indicate that rainfall was generally higher at Ear Falls than at Red Lake, and that monthly means at South Bay for June and August fell between those for Ear Falls and Red Lake, whereas the May and July means for South Bay were lower.

Table 3.1 lists monthly and summer totals for precipitation at the three stations for the years 1973 to 1986. The data for summer totals show that South Bay summer rainfall ranged from 67.7% to 120.6% of the Ear Falls totals, averaging 97.9 percent. Figure 3.2A shows that it was:

Higher than the Ear Falls and Red Lake totals in 7 years

Between the Ear Falls and Red Lake totals in 3 years

Lower than the Ear falls and Red Lake totals in 4 years

The data for monthly totals show that South Bay rainfall ranged from 48.1% to 192.2% of the Ear Falls totals, averaging 101.3 percent. Figure 3.2B shows that it was:

Higher than the Ear Falls and Red Lake totals in 18 months

Between the Ear Falls and Red Lake totals in 8 months

Lower than the Ear Falls and Red Lake totals in 23 months

Figure 3.2C is a plot of daily rainfall at South Bay vs. daily rainfall at Ear Falls on the same day; Figure 3.2D shows daily rainfall at South Bay vs. rainfall at Ear Falls one day earlier. Figure 3.2D indicates a slightly better correspondence, with fewer data points spread out along the two axes. Figures 3.3A to 3.3N allow a visual comparison of the correspondence for each of the 14 years of the South Bay record.

3.1.3. Correlation between stations

Linear regression was applied, with rainfall for Ear Falls (or Red Lake) as the independent variable, and rainfall at South Bay as the dependent variable; the intercept was forced to

zero. The data groups analyzed, and the results obtained are presented in Table 3.2, and summarized below.

SUMMER RAIN:

South Bay = 0.96 * Ear Falls (r^2 = 0.27)

South Bay = 1.02 * Red Lake (r^2 = 0.02)

MONTHLY RAIN:

South Bay = 0.93 * Ear Falls (r^2 = 0.47)

South Bay = 0.98 * Red Lake (r^2 = 0.19)

DAILY RAIN:

South BAY = 0.39 * Ear Falls SAME DAY (r^2 = -0.018)

South BAY = 0.60 * Ear Falls ONE DAY BEFORE (r^2 = 0.24)

South BAY = 0.17 * Ear Falls TWO DAYS BEFORE (? =-0.16)

South BAY = 0.19 * Ear Falls ONE DAY LATER (r^2 = -0.15)

These results indicate that both the timing and the amounts of rainfall at South Bay are poorly correlated with those at Ear Falls, and even poorer with those at Red Lake.

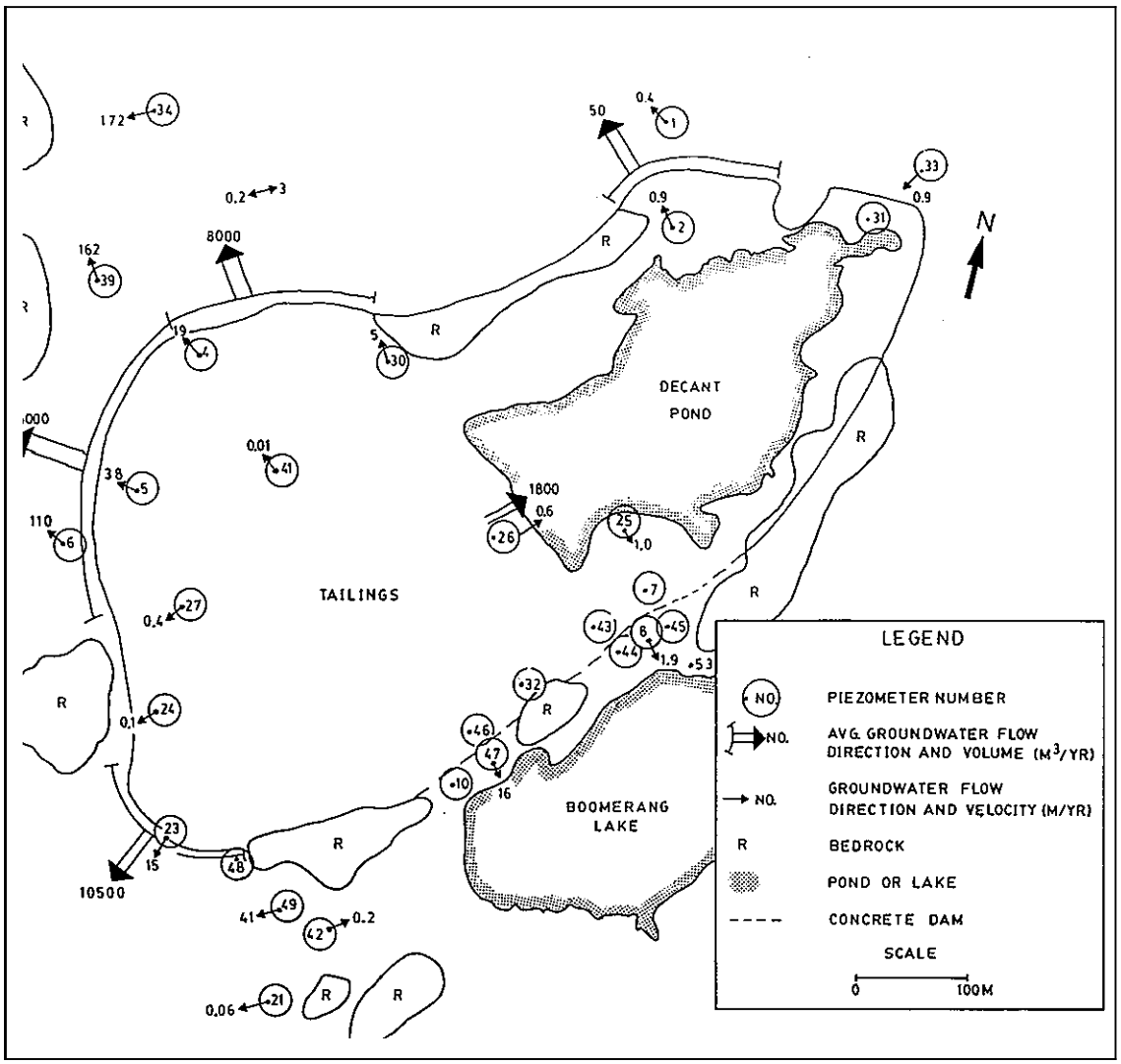
Daily rainfall data from Ear Falls should not be used for the quantitative interpretation of short-term variations in groundwater levels in the tailings at South Bay; for qualitative interpretation they may be applied, with a built-in I-day lag, but with limited confidence.

Confidence in summer and monthly data from Ear Falls is somewhat better. Long-term averages for Ear Falls rainfall appear to be reasonably representative for long-term average rainfall at South Bay.

To determine the detailed relationship between groundwater levels and local precipitation rates (and snowmelt rates) would still require operation of a recording rain gauge and a temperature recorder at South Bay during the frost-free season (and measurements of the water content of the snowpack just before the start of the snowmelt).

3.1.4. Piezometer water levels, 1990 update

Water-level records for the 26 piezometers (Map 3.1) in the tailings basin, extended with 12 measurements since October **1989,** were processed to calculate depth of water below ground (Table 3.3, Appendix 2), and water-level elevations (plotted in Figures 3.4A to 3.4E, Appendix 2).



MAP 3.1: South Bay Tailings Area with Piezometer Locations

It appears that the winter low water levels in most of the piezometers were missed by the March 27 measurements. The water levels in the piezometers rose in response to snowmelt (and late-spring rain?); several piezometers showed a second, smaller rise in water level in late summer or early fall, presumably in response to heavy rainfall.

Spring and summer highs in water level were generally similar to earlier maxima, but several piezometers showed slightly increased maximum water levels in Figure 3.4 *(or* decreased depths below ground in Table 3.3), probably as a result of high late-winter snowfall, and high rainfall in June and July. Thus, the range of water-level fluctuations increased somewhat in 19 of the 26 piezometers.

In addition to the water-level extremes and ranges, Table 3.3 also lists the maximum and minimum thicknesses of unsaturated tailings for each piezometer site. The maximum unsaturated thickness of tailings increased at 3 of the sites, while the minimum decreased at 15 of the sites, resulting in some increase in the thickness of tailings affected by water-level fluctuation in 18 of the piezometer sites.

The differences with earlier annual extremes are relatively minor. Depending on location and the time of year, anywhere from 0 to 100 percent of the total tailings thickness is unsaturated, and from 0 to 79 percent of the local total tailings thickness is affected by water-level fluctuations.

3.1.5. Precipitation, 1990 update

Precipitation data from Ear Falls for the period from October 1989 to October 1990 have been added to the existing database covering the period from October 1986 onward. A plot of daily precipitation for 1986-1990 is shown in Figure 3.5A (Appendix 2); Figure 3.56 (Appendix 2) shows monthly and annual rainfall and snowfall for the same period.

Comparison with earlier years shows that 1990 was **a** wet year. High late-winter snowfall, and high rainfall in June and July likely caused the increases in maximum water levels for some of the piezometers. The relatively large rainfall in September 1990 (90 mm) can account for the rise observed in some of the piezometers in the early fall.

3.1.6. Temperatures, 1990 update

Subsurface temperatures

Periodic temperature measurements, on the 2.44 m long cable with 11 thermistors installed near piezometer **M5,** were taken 11 times since 15 October 1989. The results are listed in Table 3.4 (Appendix 2); all measurements for the period from October 1986 to October 1990 are shown in Figures 3.6A and 3.66.

Minimum temperatures lower than those recorded during the period from October 1986 to October 1989 were measured for 5 of the thermistors during the 1989/1990 winter. These may reflect either a colder winter, a thinner snowcover, or both.

Figure 3.6C shows the observed maximum, average, and minimum temperatures vs. depth for the whole period of observation. The minimum temperature fell below 0°C only in the upper 50 cm, which would include the inert fill (reported to be an average of 15 cm thick), and the upper 30 or **40** cm of the tailings.

Figure 3.6D shows the variation of the depth to water below ground in piezometers # **4,** 5A, 58, 27A, and 278, near the thermistor string. Transient saturated conditions appear to have been limited to the level of the lower 5 thermistors, below a depth of 120 cm, and well below the maximum depth of below-zero temperatures.

The approximately monthly temperature measurements for the 1989/1990 period (with a gap of more than 3% months between **4** December 1989 and 27 March 1990) do not allow more detailed interpretation.

Air temperatures

Air temperature data from Ear Falls for the period from October 1989 to October 1990 have been added to the existing database covering the period from October 1986

onward. A plot of daily mean temperature for 1986-1990 is shown in Figure 3.6E. Comparison with the preceding years for Ear Falls indicates that the 1989/1990 winter and the 1990 summer were both colder. Extreme low daily mean temperatures were recorded in December 1989.

3.1.7. Field Data, October 1990

Field measurements of water temperature, pH, electrical potential, and conductivity were made by Boojum Research in October 1990 in a number of piezometers and surface-water bodies at the South Bay site. In 15 of the piezometers, samples for measurements and analysis were taken from both the top and the bottom of the water column in the pipe; in a few cases the piezometers were resampled after bailing.

Measured electrode potentials (Eh fld., in millivolts) were corrected for reference-electrode potential, and recalculated as pE (to simplify plotting and comparison with pH). The results are listed in Table 3.5 (Appendix 2), sorted by piezometer number. They are illustrated by Figures 3.7A to 3.7C, sorted by increasing pE value.

Figure 3.7A shows that the pH of the piezometer waters was generally higher in the bottom sample than in the top sample; Figure 3.7B shows that in most cases pE (and corrected Eh) was lower in the bottom sample than in the top sample. Eh values above 400 mV (or pE > 6.75) were associated with pH values below 4.5; Eh values below 400

mV were associated with pH values above 5.3. In all cases the Eh (corr.) was higher than 135 mV (pE > 2.28), too high to expect formation of any metal sulphides under the prevailing pH conditions.

Compared to the top samples, conductivity was higher in the bottom sample in 3 cases, the same in 10 cases, and lower in 6 cases.

3.1.8. Water analyses, October 1990

Chemical analyses (ICP and chloride, by Assayers Ontario Laboratories), as well as available field data for the samples collected from piezometers in October 1990 are listed in Table 3.6 (Appendix 2). For comparison purposes, analyses of samples collected earlier from the same piezometers are included in Table 3.6. The table also includes analyses for samples collected from various surface-water sources in October 1990. Missing data include alkalinity for samples with pH above 4.5 (19 samples); chloride (3 samples); and water temperature and Eh (3 samples).

At the bottom of the table, calculated sums of cations and anions (in equivalents per million) are given for all analyses, together with the ion-balance error values. The 1990 analyses generally have small error values; exceptions are those for M25, M27B-bottom, M55, M56, Wild Rice, and Boomerang Outflow, which have error values > 10%, and as

large as -32% and +38%). The error values compare favourably with those for some of the earlier analyses which ranged from -73% to +60%.

The pH, pE, log[Fe], and log[S] for the October 1990 samples are illustrated in Figure 3.8A. The analyses have been put in groups representing samples that are known or believed to be related. In the notations along the bottom axis of Figure 3.8A numbers represent piezometers; DB = Decant Pond beach; DO = Decant Pond outflow; WR = Milt's wild rice; MP = Mill Pond; DD = Dave's Dam; CP = Chara Pond; PP = Polishing Pond; BL = Boomerang Landing; BO = Boomerang Lake outflow; and ML = Mud Lake outflow.

Concentrations of Fe, S, Ca, and Zn for sequential samples from 10 piezometers are plotted in Figure 8B. The concentrations of these elements appear to be lower in the 1990 samples than in the most recent earlier samples for piezometers M4, M7B, M10, M30, M47, M55, and M56. In piezometers M27A and M27B the [S] and [Ca] increased, while [Zn] increased slightly in M56. [Ca] is consistently lower than [S], except in M25, M55, and M56.

3.2. Geochemical Calculations

3.2.1. Saturation degrees

For an earlier report on "Acid Generation and Inorganic Precipitate Formation at the South Bay Tailings Site", preliminary degrees of saturation with respect to gypsum were calculated for the available water analyses. However, degree of saturation with respect to other minerals was not considered. In the current study, the geochemical simulation program PHREEQE was used to evaluate the water analyses of the samples collected in October 1990 from piezometers and surface waters in the South Bay study area, for degree of saturation with respect to other minerals.

PHREEQE requires as input: pH, Eh (or pE), temperature, and concentrations of as many elements (or ions) in the water sample as possible. The elements covered by the current version of PHREEQE include Ag, Al, As, B, Ba, Br, C, Ca, Cd, Cl, Cs, Cu, F, Fe, I, K, Li, Mg, Mn, Mo, N, Na, Nd, Ni, P, Pb, Rb, S, Se, Si, Sr, U, V, and Zn. The program will calculate concentrations for all aqueous species represented by the element input, and degrees of saturation of the water with respect to numerous minerals that consist of various combinations of the elements found in the analysis.

PHREEQE can also simulate several types of reactions, including (1) addition of inorganic reactants to a solution, (2) mixing of two waters, and (3) titrating one solution with

another. In each of these cases PHREEQE can maintain the reacting solution at equilibrium simultaneously with one or more user-specified minerals.

The program calculates the following quantities during each reaction simulation:

1 pH.

2 pE (electron activity, representing Eh).

3 The total concentrations of elements.

4 The amounts of minerals (or other phases) transferred into or out of the aqueous phase during a reaction.

5 The distribution of aqueous species.

6 The saturation state of the aqueous phase with respect to specified mineral phases.

3.2.2. Analyses used

All analyses for the October 1990 samples have been used (see Table 3.7, Appendix 2). Missing data for alkalinity, chloride, Eh, and temperature are flagged in Table 3.7. Estimated values were used where temperature and Eh data were not available.

3.2.3. Results and Discussion

Output from the single-solution simulations (approximately 170 pages) was edited to reduce the amount of paper and printer time required. Table 3.7 shows the significant data for each of the 30 simulations, including:

Sample identification

Flags for missing data

Ion-balance errors from Table 3.3

Values for the "saturation index" LOG [IAP/KT] (i.e., the logarithm of the ratio of the ion-activity product IAP and the equilibrium constant KT), for all minerals for which positive values (indicating saturation) were found in any of the samples. Only the values larger than -1.000 are shown in Table 3.7, to improve readability.

All samples except that from Dave's Dam show super-saturation (positive LOG[IAP/KT]) to various degrees with respect to several **iron minerals,** including ferric hydroxides, goethite, hematite, lepidocrocite, and maanetite, which may be precipitated. Super-saturation with respect to jarosite is shown only by samples from M10 and M47 (and Mill Pond).

Samples from the bottom of M4 and from Boomerang Landing show super-saturation with respect to several **aluminum minerals;** those from M4, M10, Mill Pond, Dave's Dam, and Boomerang Landing show super-saturation with respect to several clay minerals.

Samples from M7B, M10, M25, M30, M47, M55, Mill Pond, and Dave's Dam show super-saturation with respect to **quartz.** Samples from M7B, M10, and M47 show super-saturation with respect to **gypsum.**

It should be pointed out here that apparent saturation with respect to a particular mineral does not necessarily mean that mineral will be precipitated from the water. Where super-saturation with respect to several iron compounds and aluminum compounds is indicated, those with the highest saturation index may be the first to be precipitated.

It should also be stressed that the excessively large apparent saturation indices for some of the iron minerals (e.g., hematite and maanetite) are likely the result of the samples having been exposed to air, affecting the pE values.

3.2.4. Oxidation and precipitation rates

Using the new maximum and minimum water levels from Table 3.3 (Appendix 2), the available chemical analyses, and the same estimated recharge rate as in the earlier report on this study, new sulphide-oxidation and Fe-precipitation rates have been calculated.

The results are shown in Table 3.8. The rates are only fractionally different from those listed in the addendum to the earlier report (dated 30 January 1990).

The revised sulphide-oxidation rates range from 0.0001 to 0.0427 $mol.kg^{-1}.yr^{-1}$ (Overall average 0.0033 $mol.kg^{-1}.yr^{-1}$). Because of temperature effects, rates can be expected to be higher than this in summer, and lower in winter.

The revised Fe-precipitation rates range from 0.000009 to 0.001135 $mol.kg^{-1}.yr^{-1}$ (overall average 0.00025 $mol.kg^{-1}.yr^{-1}$). Precipitation might be enhanced by infiltration of rain and snowmelt with higher pH.

3.2.5. Future geochemical studies

Future geochemical studies would be enhanced if temperature, pH, Eh, and alkalinity for waters with pH above 4.5 are determined for **all** samples at the time of sample collection.

ICP analysis of filtered/acidified samples should be complemented by analysis of filtered/non-acidified samples for: Cl, F, and total inorganic carbon for samples with pH below 4.5.

3.3. Precipitate Descriptions

Tailing samples were obtained from two sites, M-24 and M-27, to determine the degree of secondary mineralizationwithin the tailings and the species of newly formed minerals within the precipitate. M-24 and M-27 refer to piezometer locations. The samples were collected during a fieldtrip from October 11 - 13, **1990.** Originally it was planned to obtain a complete vertical section of the tailings by driving a 4" pipe into the tailings. This method was unsuccessful because of the lack of cohesion and the degree of saturation of the tailings. Subsequently a backhoe was used to dig a narrow trench at both localities and the samples were collected from the trench wall. The samples were examined visually and described (Appendix 3), and a number of samples were submitted for SEM. Energy dispersive X-ray microanalysis was used extensively to determine elemental composition of the targets selected (Appendix **4).** The latter analyses were conducted by Integrity Testing Laboratory in Toronto.

3.3.1. Stratigraphy

Stratigraphy Trench M-24.

The tailings at location M-24 are overlain by about 70 cm of sandy and gravelly fill. The fill is oxidized (Plate 3.1). It is not known if the material used for the fill was already oxidized at the time of placement or if the oxidation occurred after placement. The upper

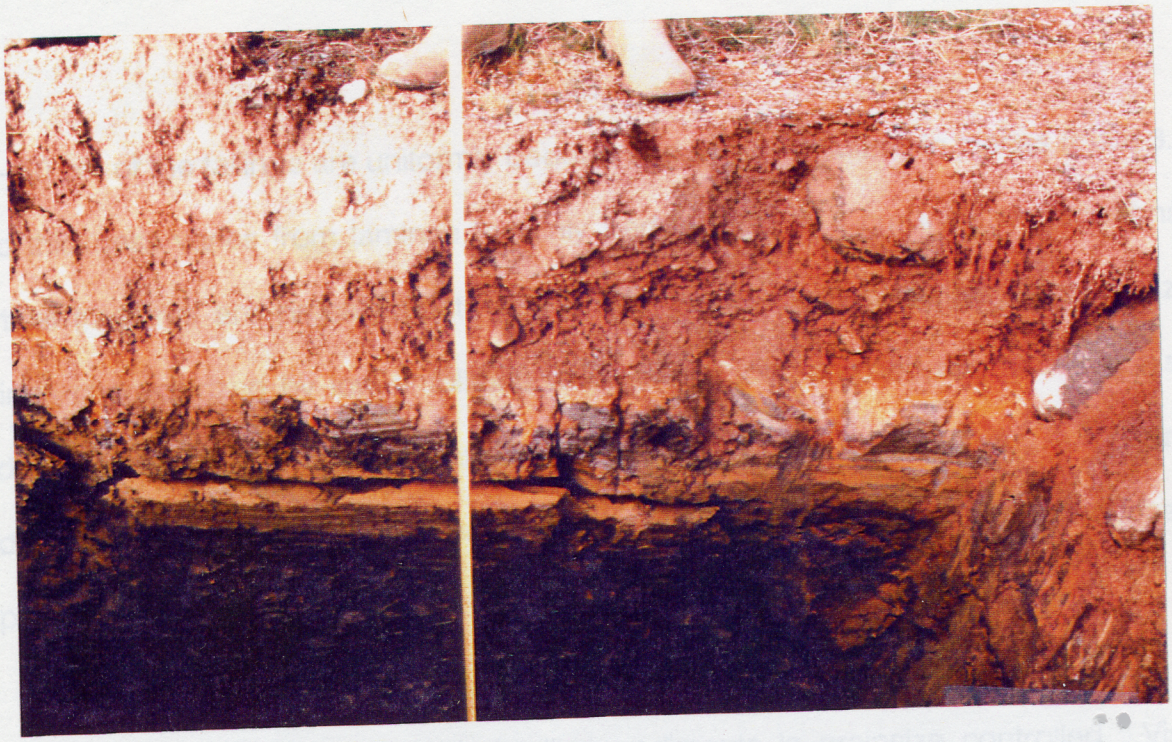


Plate 3.1: Trench at M-24. (Note fractures in tailings below boots).

Plate 3.2: Top of tailings, M-24. (Note well-defined oxidized beds).

45 - 50 cm of the tailings are uniformly bedded and deeply oxidized in places (Plate 3.2). Bed thickness varies from laminae to thinly bedded (up to 4 cm thick). Occasionally vertical fractures are present (Plate 3.1). This sequence is underlain by unoxidized tailings characterized by low amplitude wavy and discordant bedding and minor *soft* sediment deformation. This type of sedimentary structure is typical of very fine grained sediments which were deposited subaqueously and subsequently underwent subaerial exposure.

Oxidation in the upper well-bedded tailing sediments is grainsize controlled. Visual examination of samples clearly indicates that only the coarser grained well sorted beds and laminae within a sequence show signs of Fe oxide/hydroxide coating and /or precipitation. The contact between beds with rustbrown discolouring and unoxidized surrounding beds varies from sharp, (i.e. coincides with the bed (laminae) boundary), to gradational. Throughout the section thin beds and laminae comprising predominantly well sorted quartz grains are present. It is thought that these beds and laminae are wind-blown in origin.

Stratigraphy Trench M-27.

The tailings at location M-27 are overlain by 25 - 30 cm of oxidized sandy and gravelly fill (Plate 3.3). Immediately underlying the fill is an irregular light gray bed which consists predominantly of siltsize to very fine grained quartz. Within this bed thin yellow (ox) beds and laminae, laterally discontinuous, are present. Numerous irregular Fe oxide/hydroxide

Plate 3.3: Trench at M-27. (Note irregular fractures to the right of tape).

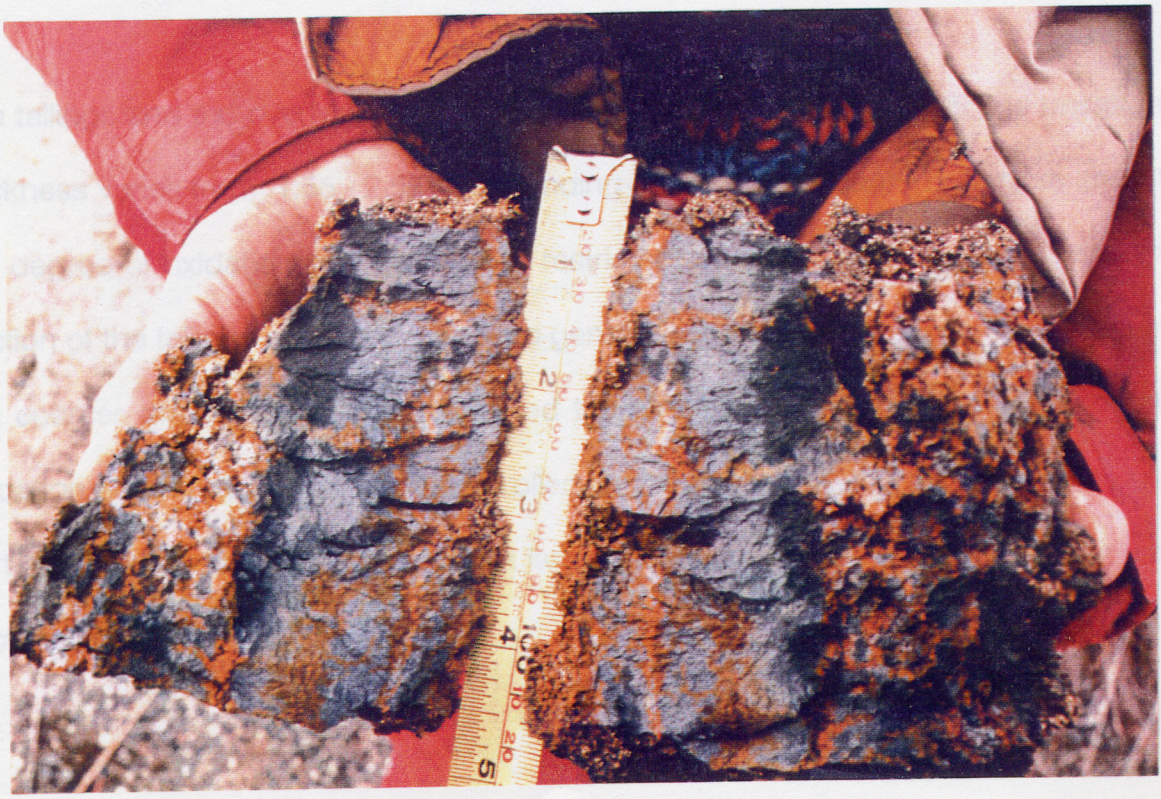


Plate 3.4: Infilled and oxidized desiccation fractures, M-27.

stained near-vertical "fractures" are present in this bed (Plate **4).** The oxidized vertical "fractures" contain sediment coarser than the surrounding material. They most likely are infilled desiccation cracks. The lower contact is very irregular and shows indications of ***soft*** sediment deformation. The tailings underlying the light gray bed are thinly bedded to laminated. Bedding is discordant in places and the exposed section appears to have undergone differential compaction and/or minor ***soft*** sediment deformation. Thin greyish and yellow to rust brown coloured quartz rich beds and laminae, laterally discontinuous, and irregular lenses are common throughout the upper part of this sequence. Fe oxide/hydroxide coating and/or precipitation is essentially restricted to these quartz-rich beds and laminae (Plates 5,6). It is thought that most of the quartz-rich beds and lenses are wind blown in origin. The section of tailings which exhibits oxidation varies from **20 -** 30 cm in thickness.

The tailings and the overlying fill are unsaturated at **M-24,** while at **M-27** the unsaturated thickness varies from 1.55 **- 2.55** m depending on the time of year. Both sites show that the degree of oxidation in the tailings is restricted to the upper part of the unsaturated section of the tailings and the oxidation is generally restricted to beds and laminae which are coarser grained and/or better sorted than the surrounding beds. The depth of oxidation appears to be primarily controlled by the permeability distribution in the upper part of the unsaturated tailings and to a larger extent by the thickness of the unsaturated section.

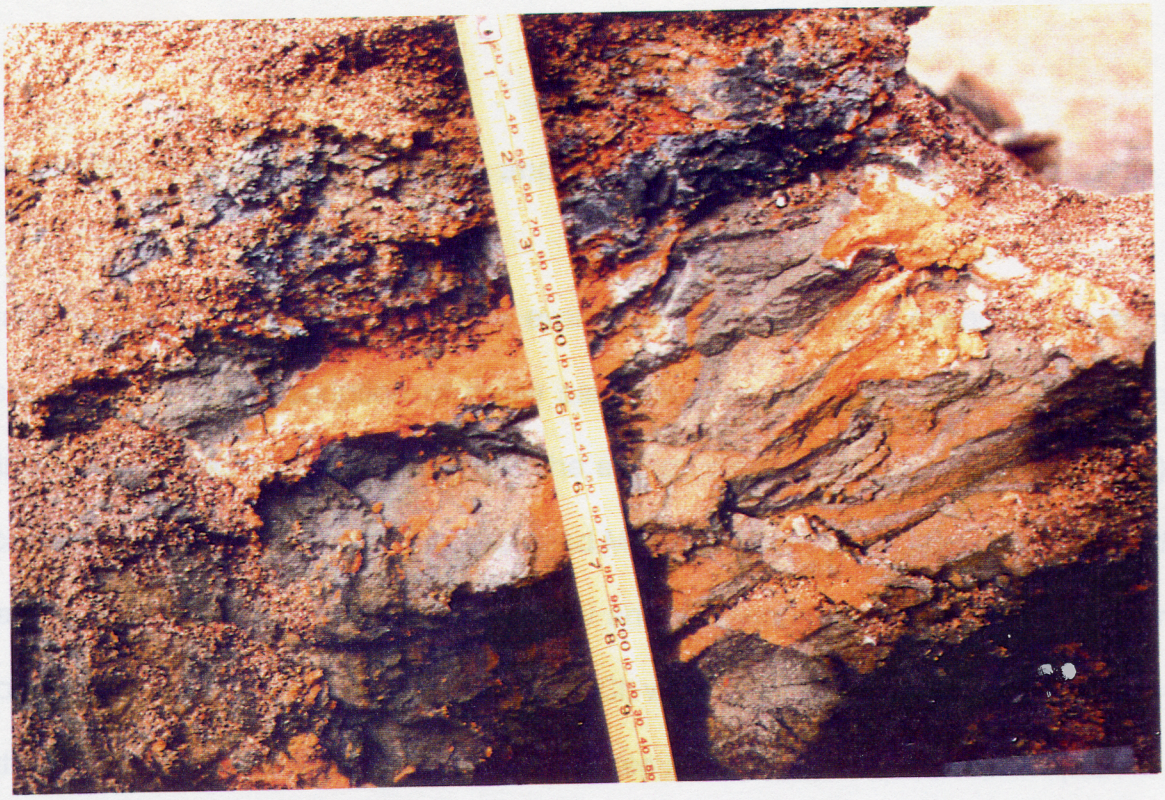


Plate 3.5: Oxidized laterally discontinuous sand beds, M-27.

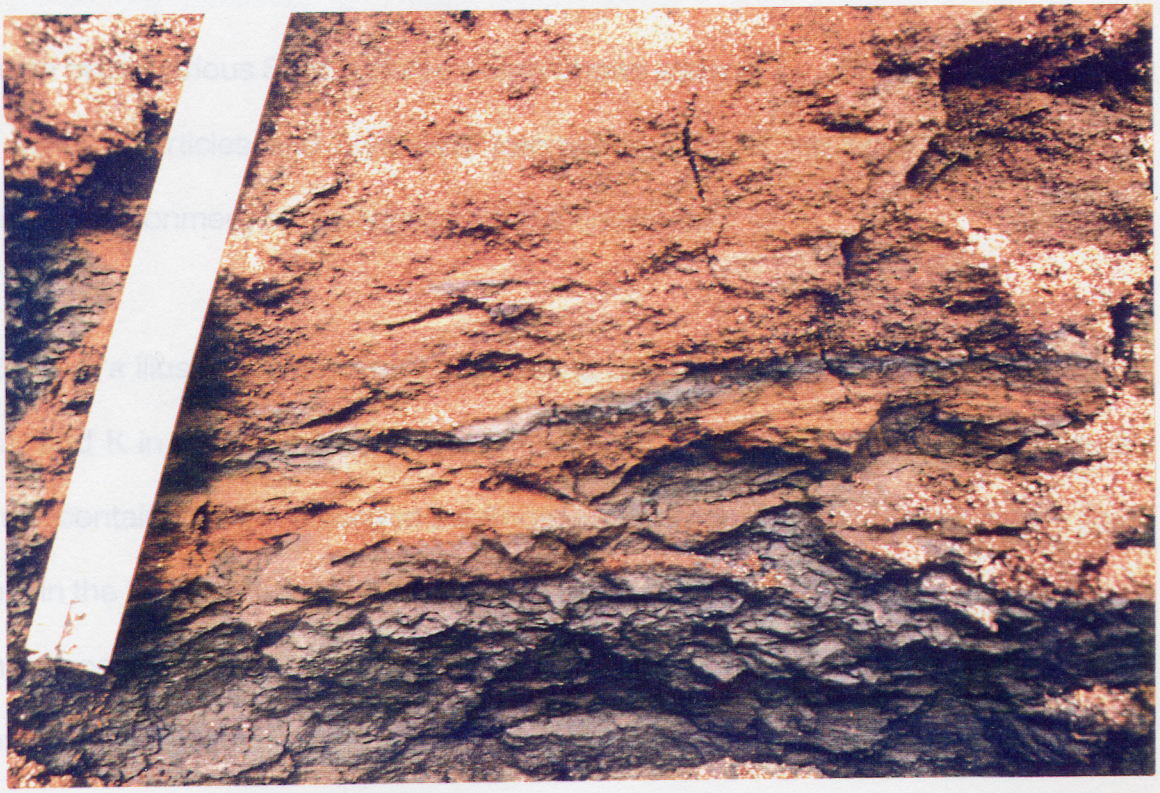


Plate 3.6: Oxidized laterally discontinuous sand beds and laminae, M-27.

3.3.2. Scanning Electron Micrographs and Energy Dispersive X-Ray Analysis

Two samples, M 24-4 and M 27-3, were examined in detail with a scanning electron microscope. A visual description of these samples is included in Appendix 3. The scanning electron micrographs (SEM) and the energy dispersive x-ray analyses (EDS) are included in Appendices 4 and 5 for M24 and M273 respectively. It should be pointed out that the samples were embedded in epoxy and subsequently coated prior to their insertion in the SEM. The epoxy will introduce Cl, while the coating will introduce Al or Au in the EDS spectra. The EDS spectra in Figures A4/2, A4/9, and A4/10, sample 1M-244 were obtained from an Al coated specimen. All other EDS spectra shown in Appendices 4 and 5 were obtained from Au coated specimens.

Examination of the various SEM pictures clearly shows etching, i.e. differential dissolution, of most mineral particles and crystalline fragments. This is not too surprising if the geochemical environment of the tailings area is considered.

The EDS spectra illustrate the presence of Fe and S in all analyses and the presence of Si, Al, Na, and K in most analyses. These elements are common in the metavolcanic rocks which contained the ore body at the South Bay mine and consequently should also be present in the tailing deposits. Geochemical simulations show that these elements are common components of the various minerals which could precipitate in this environment. Unfortunately EDS analysis does not provide information on the species of ion which

contains a particular element. For example, if S is detected it could be present as sulphur, sulphide or sulphate. Furthermore, EDS cannot analyze for the elements H and O. It should also be recognized that EDS spectra are essentially qualitative. and elemental composition, expressed as weight percentage, is semiquantitative. It is obvious from the foregoing that the interpretation of multi-element EDS spectra can only be speculative, because of a lack of distinction between the elemental composition of the primary minerals (metavolcanics, sulphides) and the secondary minerals (precipitates). There is no possibility of identifying the ion source of the element and no information can be obtained for the elements H and O, or the quantitative distribution of the elements.

In order to determine if the mineral fragments were coated, EDS spectra were obtained from the same target area using different energy levels.

3.4. Conclusions

The timing and amounts of rainfall at South Bay during the months of May to September are poorly correlated with those at Ear Falls, and even poorer with those at Red Lake. There are no precipitation data available for South Bay outside the above period.

Daily rainfall data from Ear Falls should not be used for the quantitative interpretation of short-term variations in groundwater levels in the South Bay tailings; for qualitative interpretation they may be applied, with a built-in 1-day lag, but with limited confidence.

Confidence in summer and monthly data from Ear Falls is somewhat better. Long-term averages for Ear Falls rainfall appear to be reasonably representative for long-term average rainfall at South Bay.

Several piezometers showed increased maximum water levels in 1990, as a result of high late-winter snowfall and early-summer rains. The range of water-level fluctuations increased in 19 of the 26 piezometers.

The maximum unsaturated thickness of tailings increased at **3** of the sites, while the minimum decreased at 15 of the sites, resulting in some increase in the thickness of tailings affected by water-level fluctuation in 18 of the piezometer sites.

Depending on location and season, 0 to 100 percent of the total tailings thickness is unsaturated, and from ***0*** to 79 percent of the local total tailings thickness is affected by water-level fluctuations.

During the 1989/1990 winter, minimum measured ground temperatures fell below 0°C in the upper 50 cm, which includes the inert fill (reported to be an average of 15 cm thick),

and the upper 30 or 40 cm of the tailings. Transient saturated conditions appear to have been limited to the level of the lower 5 thermistors, below a depth of 120 cm, and well below the maximum depth of below-zero temperatures.

The concentrations of Fe, S, Ca, and Zn are lower in the October **1990** samples than in earlier samples for most of the piezometers. [S] and [Ca] increased in M27A and M27B, while [Zn] increased slightly in M56.

All piezometer samples show super-saturation with respect to several **iron minerals,** including ferric hydroxides, goethite, hematite, lepidocrocite, and maanetite, which may be precipitated. Super-saturation with respect to jarosite is shown only by samples from 2 piezometers and Mill Pond.

Samples from M4 and M10 (and from Mill Pond and Boomerang Landing) show super-saturation with respect to several **aluminum minerals,** including alunite, boehmite, diaspore, gibbsite, and several clay minerals.

Samples from M7B, M10, M25, M30, M47, M55, Mill Pond, and Dave's Dam show super-saturation with respect to **quartz;** those from M7B, M10, and M47 also show super-saturation with respect to **gypsum.**

Revised sulphide-oxidation rates range from 0.0001 to 0.0427 $mol.kg^{-1}.yr^{-1}$ (overall average 0.0033 $mol.kg^{-1}.yr^{-1}$). Revised Fe-precipitation rates range from 0.000009 to 0.001 135 $mol.kg^{-1}.yr^{-1}$ (overall average 0.00025 $mol.kg^{-1}.yr^{-1}$).

It appears that several mineral fragments ware coated with Alunite (?), (Na,(K),Al,S) or Fe sulphate/hydroxysulphate (Fe,S). In all likelihood these compounds were formed as evaporates when the sample was dried prior to the SEM analysis. The cluster of crystals shown in Figure A4/8, 1M-244, is thought to be Alunite and formed in this manner.

The crystals in Figure A4/4, 1M-244, in all likelihood are Jarosite (Na(k),Fe,S).

The needle like crystals in Figures A4/9 and A4/10 are a form of quartz.

4.0 RECOMMENDATIONS

In the area of biological polishing it is proposed that a research program be setup to test the feasibility of the eventual use of macroalgal populations as biological polishing agents at mine sites. Year 1 of this proposal is basically a scale-up feasibility study. Field data and laboratory corroboration need to be collected for a variety of biological and geochemical parameters involved in metal sequestration. Measurements of growth rates, density, uptake and sequestration rates, and limiting factors will be made. A model will be developed for the prediction of biological polishing capacity of a scaled-up system.

Concurrent with these growth studies, techniques for the establishment of algal populations in mine waste water will be developed. This includes development of the proper substrate and nutrient environment, and flow regimes for optimal production and biopolishing. Finally, the first year's work will formulate a working hypothesis of the limiting factors involved, the optimal conditions necessary, and the feasibility of commercial scale-up.

Year 2 will be spent optimizing and refining the working hypothesis and feasibility study for implementation at several mine sites. This will require both field and lab work.

Once the feasibility study has been accepted, refined and biological and geochemical parameters optimized, the system is ready for commercial scale-up. The third year will determine those scale-up parameters necessary to commercialize the process.

Measurements of water levels in all operational piezometers should be continued, ideally on a weekly basis. Excessive gaps in the water level record, like those from **23-8-88** to **22-7-89,** and from **4-12-89** to **27-3-90,** should be prevented.

Determination of the detailed relationship between groundwater levels and local rates of precipitation (and snowmelt), would require the operation of a recording rain gauge and a temperature recorder at South Bay during the frost-free season (and measurements of the water content of the snowpack just before the start of the snowmelt).

For monitoring purposes, water samples for chemical analysis should be collected at least from all the piezometers around the tailings basin, at the same time, and at least once a year.

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5.0 APPENDICES

APPENDIX 1: 610-POLISHING BIBLIOGRAPHY

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COMPARISON OF RAINFALL, 1973 - 1986

MONTHLY:

YEAR	SOUTH BAY	RED LAKE	EAR FALLS
1973	78.8	111.5	107.8
	52.2	72.6	70.8
	106.0	149.9	171.7
1974	123.4	56.1	104.9
	118.7	159.0	89.1
	212.4	157.2	183.0
1975	94.9	146.3	107.2
	93.3	144.5	104.8
	117.0	118.9	129.3
	43.3	60.2	60.8
1976	132.6	53.6	128.1
	62.6	58.2	55.8
	59.6	48.0	39.4
	55.5	50.5	42.3
1977	83.2	54.4	84.9
	111.4	133.9	116.7
	101.1	115.0	119.6
	116.6	91.9	103.0
1978	109.9	126.4	101.6
	191.8	79.0	111.1
	66.8	71.6	93.2
1979	50.9	31.3	61.4
	77.1	55.1	70.1
	127.0	133.3	195.5
1980	90.4	80.0	70.2
	46.5	62.1	51.2
	139.9	86.3	131.5
1981	57.7	100.9	117.8
	82.8	34.2	48.8
	75.6	95.3	92.8
1982	112.0	103.3	68.7
	83.8	90.6	93.7
	75.3	49.8	70.9
1983	39.5	43.8	54.9
	85.5	96.1	136.9
	89.6	55.9	92.5
	101.8	76.4	63.7
1984	80.0	59.7	110.7
	113.4	132.8	127.7
	70.4	107.1	86.5
	36.7	61.8	76.3
1985	166.3	170.2	166.2
	76.1	40.7	39.6
	116.8	124.0	143.8
1986	19.6	26.1	31.0
	84.6	84.9	52.6
	38.2	70.3	67.9
	94.5	52.1	76.7
	151.9	116.0	141.4

SUMMER:

YEAR	SOUTH BAY	RED LAKE	EAR FALLS
1973	237.0	334.0	350.3
1974	454.5	372.3	377.0
1975	348.5	469.9	402.1
1976	310.3	210.3	265.6
1977	412.3	395.2	424.2
1978	368.5	277.0	305.9
1979	255.0	219.7	327.0
1980	276.8	228.4	252.9
1981	216.1	230.4	259.4
1982	271.1	243.7	233.3
1983	316.4	272.2	348.0
1984	300.5	361.4	401.2
1985	359.2	334.9	349.6
1986	388.8	349.4	369.6

RAINFALL CORRELATIONS
1973-1986

SOUTH BAY vs. EAR FALLS (summer):
Regression Output:

Constant	0
Std Err of Y Est	59.25336
R Squared	0.271009
No. of Observations	14
Degrees of Freedom	13
X Coefficient(s)	0.958288
Std Err of Coef.	0.046784

SOUTH BAY vs. RED LAKE (summer):
Regression Output:

Constant	0
Std Err of Y Est	68.69164
R Squared	0.020276
No. of Observations	14
Degrees of Freedom	13
X Coefficient(s)	1.020294
Std Err of Coef.	0.058055

SOUTH BAY vs.EAR FALLS (monthly):
Regression Output:

Constant	0
Std Err of Y Est	28.41990
R Squared	0.469549
No. of Observations	49
Degrees of Freedom	48
X Coefficient(s)	0.933442
Std Err of Coef.	0.039531

SOUTH BAY vs. RED LAKE (monthly):
Regression Output:

Constant	0
Std Err of Y Est	35.13323
R Squared	0.189344
No. of Observations	49
Degrees of Freedom	48
X Coefficient(s)	0.980354
Std Err of Coef.	0.052533

SOUTH BAY vs.EAR FALLS (daily):
Regression Output:

Constant	0
Std Err of Y Est	6.404095
R Squared	-0.01826
No. of Observations	1883
Degrees of Freedom	1882
X Coefficient(s)	0.385370
Std Err of Coef.	0.020828

SOUTH BAY vs.EAR FALLS (daily, +1d):
Regression Output:

Constant	0
Std Err of Y Est	5.519818
R Squared	0.243887
No. of Observations	1882
Degrees of Freedom	1881
X Coefficient(s)	0.598750
Std Err of Coef.	0.017952

SOUTH BAY vs.EAR FALLS (daily, -1d):
Regression Output:

Constant	0
Std Err of Y Est	6.857633
R Squared	-0.16710
No. of Observations	1882
Degrees of Freedom	1881
X Coefficient(s)	0.171109
Std Err of Coef.	0.022308

SOUTH BAY vs.EAR FALLS (daily, +2d):
Regression Output:

Constant	0
Std Err of Y Est	6.831929
R Squared	-0.15771
No. of Observations	1881
Degrees of Freedom	1880
X Coefficient(s)	0.191036
Std Err of Coef.	0.022220

TABLE 3. WATERLEVELS, 1986/90

DEPTH of WATER below GROUND, m

Piezom. No.	*	15-Oct-86 31700 XXXXX	05-Nov-86 31721 XXXXX	22-Nov-86 31738	30-Nov-86 31746	07-Dec-86 31753	14-Dec-86 31760	21-Dec-86 31767	28-Dec-86 31774	04-Jan-87 31781	11-Jan-87 31788	25-Jan-87 31802
4	B	3.20	3.23	3.26	3.29	3.31	3.33	3.37	3.35	3.37	3.38	3.40
5A	B	3.29	3.38	3.44	3.47	3.49	3.52	3.52	3.54	3.56	3.57	3.59
5B	B	2.01	2.74							2.85	2.85	2.88
7A	T	2.44	2.53							2.87	2.84	2.93
7B	B	2.80	2.83							3.09	3.08	3.14
9	B	3.38	3.32	3.42	3.45	3.47	3.50	3.50	3.53	3.54	3.54	3.58
24A	B	3.26	3.38	3.52	3.53	3.56	3.59	3.61	3.63	3.65	3.65	3.69
24B	B	3.20	3.26	3.42	3.45	3.48	3.51	3.52	3.55	3.56	3.58	3.61
25	B	0.58	0.58							0.83	0.82	0.90
26	B	0.64	0.70							0.79	0.74	0.85
27A	T	1.16	1.58							2.15	2.32	2.29
27B	T	0.49	1.25							1.87	1.86	2.03
30	B	0.37	0.61							0.79	0.79	0.91
32	B	3.20	3.20							3.41	2.99	3.46
40	B	1.74	2.13							2.35	2.35	2.53
41	B	0.31	0.40							0.71	0.70	0.95
43	B	2.07	2.44							2.79	2.77	2.96
46	B	3.69	3.41	3.53	3.58	3.59	3.60	3.63	3.65	3.66	3.66	3.72
H1	T	1.19	1.37	1.68	1.71	1.74	1.78	1.78	1.81	1.81	1.87	1.95
H2	T	1.62	1.77	2.03	2.07	2.10	2.13	2.15	2.17	2.20	2.22	2.30
H3	T	1.61	1.86	2.21	2.24	2.26	2.30	2.33	2.36	2.40	2.41	2.55
H4	T	0.31	0.40	0.72	0.74	0.79	0.84	0.83	0.86	0.88	0.86	1.14
H5	T	0.37	0.49	0.67	0.70	0.73	0.77	0.77	0.79	0.81	0.81	0.98
H6	T	1.37	1.49	1.68	1.74	1.75	1.79	1.78	1.81	1.81	1.82	1.91
H7	T	1.62	1.71	1.87	1.87	1.90	1.94	1.93	1.95	1.96	1.97	2.06
H8	T	0.61	0.73	1.00	1.00	1.06	1.09	1.07	1.09	1.11	1.10	1.35

* T - in tailings; B - in sediment below tailings

TABLE 3. WATERLEVELS, 1986/90

DEPTH of WATER below GROUND, m

Piezom. No.	*	08-Feb-87 31816	15-Feb-87 31823	21-Feb-87 31829	01-Mar-87 31837	15-Mar-87 31851	29-Mar-87 31865	15-Apr-87 31882	29-Apr-87 31896	06-May-87 31903	14-May-87 31911	23-May-87 31920
4	B	3.43	3.44	3.44	3.43	3.45	3.35	3.05	3.12	3.17	3.23	3.25
5A	B	3.63	3.64	3.66	3.64	3.64	3.56	3.19	3.27	3.32	3.38	3.41
5B	B	2.88	2.89	2.88	2.93	2.91	2.78	2.24	2.29	2.39	2.48	2.53
7A	T	2.98	2.99	3.02	3.01	3.02	2.81	2.31	2.37	2.41	2.55	2.61
7B	B	3.19	3.20	3.22	3.22	3.19	2.99	2.49	2.67	2.69	2.86	2.89
9	B	3.63	3.65	3.67	3.65	3.66	3.52	2.98	3.07	3.11	3.23	3.28
24A	B	3.71	3.72	3.71	3.74	3.75	3.65	3.25	3.32	3.37	3.43	3.45
24B	B	3.64	3.66	3.68	3.68	3.69	3.61	3.09	3.13	3.20	3.29	3.33
25	B	0.94	0.94	0.93	0.96	0.94	0.74	0.28	0.43	0.49	0.60	0.62
26	B	0.89	0.87	0.88	0.84	0.79	0.66	0.63	0.71	0.76	0.82	0.80
27A	T	2.41	2.43	2.43	2.44	2.34	1.89		1.34	1.37	1.79	1.77
27B	T	2.17	2.19	2.20	2.21	2.09	1.56		1.02	1.05	1.56	1.51
30	B	0.94	0.96	0.96	0.94	0.89	0.45	0.32	0.46	0.47	0.61	0.47
32	B	3.51	3.52	3.50	3.53	3.51	3.34	2.81	2.96	3.00	3.13	3.17
40	B	2.59	2.62	2.64	2.58	2.49	2.00	1.80	2.05	2.07	2.27	2.09
41	B	1.11	1.12	1.14	1.13	0.97	0.57	0.34	0.51	0.55	0.81	0.72
43	B	2.92	2.94	2.94	2.96	2.95	2.69	1.95	2.17	2.18	2.39	2.45
46	B	3.76	3.68	3.80	3.78	3.78	3.61	3.08	3.21	3.29	3.38	3.42
H1	T	1.96	1.96	1.96	1.96	1.95	1.21	0.56	1.16	1.40	1.61	1.48
H2	T	2.37	2.42	2.45	2.47	2.41	2.02	1.57	1.74	1.83	1.93	1.88
H3	T	2.68	2.71	2.73	2.75	2.61	2.05	1.08	1.62	1.82	2.01	1.96
H4	T	1.25	1.27	1.32	1.25	1.08	0.24	0.13	0.52	0.79	0.97	0.71
H5	T	1.08	1.11	1.13	1.12	0.98	0.33	0.19	0.46	0.63	0.75	0.59
H6	T	1.99	2.03	2.02	2.05	1.98	1.50	1.11	1.38	1.48	1.61	1.51
H7	T	2.15	2.17	2.16	2.20	2.09	1.65	1.46	1.63	1.71	1.81	1.70
H8	T	1.50	1.52	1.55	1.52	1.30	0.56	0.50	0.82	1.04	1.22	0.96

* T - in tailings; B - in sediment below tailings

TABLE 3. WATERLEVELS, 1986/90

DEPTH of WATER below GROUND, m

Piezom. No.	*	03-Jun-87 31931	11-Jun-87 31939	20-Jun-87 31948	28-Jun-87 31956	05-Jul-87 31963	18-Jul-87 31976	15-Aug-87 32004	25-Sep-87 32045	06-Oct-87 32056	12-Nov-87 32093	14-Dec-87 32125
4	B	3.24	3.25	3.28	3.32	3.34	3.35	3.40	3.43	3.44	3.43	3.44
5A	B	3.40	3.42	3.44	3.48	3.51	3.52	3.56	3.62	3.62	3.64	3.64
5B	B	2.55	2.55	2.55	2.60	2.65	2.66	2.67	2.68	2.71	2.72	2.74
7A	T	2.63	2.48	2.51	2.58	2.59	2.71	2.78	2.91	2.97	3.00	3.10
7B	B	2.91	2.79	2.83	2.91	2.94	2.98	3.07	3.18	3.23	3.25	3.37
9	B	3.33	3.26	3.31	3.36	3.40	3.45	3.52	3.61	3.66	3.68	3.74
24A	B	3.49	3.51	3.53	3.58	3.59	3.62	3.67	3.72	3.73	3.73	3.75
24B	B	3.36	3.36	3.40	3.44	3.47	3.51	3.59	3.65	3.68	3.67	3.70
25	B	0.65	0.54	0.59	0.66	0.71	0.73	0.80	0.93	0.98	0.97	1.05
26	B	0.82	0.66	0.73	0.80	0.81	0.83	0.83	0.95	0.99	0.86	1.04
27A	T	1.77	1.75	1.85	2.00	2.05	2.00	2.10	2.35	2.43	2.44	2.55
27B	T	1.52	1.54	1.63	1.81	1.84	1.78	1.88	2.17	2.24	2.21	2.38
30	B	0.50	0.40	0.44	0.51	0.60	0.63	0.75	1.07	0.89	1.01	1.13
32	B	3.20	3.11	3.14	3.21	3.26	3.30	3.38	3.49	3.54	3.56	3.63
40	B	2.03	1.98	2.13	2.14	2.19	2.12	2.22	2.55	2.47	2.53	2.72
41	B	0.75	0.34	0.44	0.49	0.49	0.58	0.59	0.95	0.99	0.88	1.25
43	B	2.48	2.33	2.36	2.45	2.46	2.57	2.67	2.80	2.89	2.90	3.03
46	B	3.41	3.36	3.40	3.47	3.56	3.56	3.62	3.74	3.80	3.79	3.87
H1	T	1.22	1.34	1.48	1.70	1.76	1.70	1.86				
H2	T	1.73	1.82	1.85	2.00	2.07	2.06	2.19	2.45	2.52	2.55	2.66
H3	T	1.71	1.84	1.94	2.14	2.25	2.24	2.45	2.78			
H4	T	0.44	0.53	0.88	1.20	1.14	0.99	1.12	1.46	1.37	1.31	1.51
H5	T	0.46	0.48	0.70	0.92	0.94	0.81	0.95	1.22	1.17	1.11	1.31
H6	T	1.44	1.43	1.51	1.66	1.71	1.71	1.86	2.04	2.09	2.11	2.22
H7	T	1.66	1.62	1.66	1.82	1.88	1.79	1.92	2.14	2.18	2.24	2.28
H8	T	0.69	0.78	1.05	1.34	1.34	1.17	1.31	1.65	1.68	1.48	1.76

* T - in tailings; B - in sediment below tailings

TABLE 3. WATERLEVELS, 1986/90

DEPTH of WATER below GROUND, m

Piezom. No.	*	17-Jan-88 32159	08-Apr-88 32241	25-Apr-88 32258	16-Jun-88 32310	23-Aug-88 32378	22-Jul-89 32711	26-Aug-89 32746	09-Sep-89 32760	23-Sep-89 32774	07-Oct-89 32788
4	B	3.49	3.39	3.19	3.37	3.34	3.27	3.34	3.29	3.18	3.25
5A	B	3.67	3.74	3.37	3.53	3.47	3.39	3.47	3.37	3.30	3.38
5B	B	2.80	2.88	2.56	2.45	2.15	1.83	1.92	1.81	1.69	1.84
7A	T	3.11	3.09	2.65	2.77	2.47	2.35	2.42	2.22	2.12	2.33
7B	B	3.42	3.40	2.98	3.03	2.85	2.73	2.87	2.65	2.52	2.68
9	B	3.80	3.78	3.39	3.48	3.33	3.27	3.36	3.17	3.10	3.24
24A	B	3.77	3.95	3.46	3.60	3.45	3.38	3.46	3.41	3.26	3.36
24B	B	3.75	3.71	3.39	3.52	3.48	3.41	3.46	3.40	3.31	3.38
25	B	1.12		0.64	0.77	0.62	0.53	0.59	0.50	0.34	0.49
26	B	1.07	0.89	0.74	0.85	0.75	0.73	0.71	0.65	0.65	0.69
27A	T	2.70	2.54	1.64	2.09	2.12	1.82	1.85	1.81	1.30	1.55
27B	T	2.56	2.31	1.02	1.85	1.74	1.66	1.74	1.69	1.07	1.40
30	B	1.37	0.47		0.64	0.83	0.71	0.75	0.69	0.55	0.62
32	B	3.70	3.64	3.22	3.35	3.19	3.11	3.18	3.08	2.92	3.08
40	B	2.90	2.25	1.94	2.17	2.27	2.19	2.18	2.15	1.92	2.10
41	B	1.61	1.33	0.57	0.82	0.68	0.52	0.50	0.44	0.35	0.50
43	B	3.13	3.13	2.51	2.63	2.34	2.21	2.30	2.23	1.95	2.18
46	B	3.93	3.88	3.46	3.60	3.44	3.36	3.44	3.37	3.18	3.33
H1	T			1.04	1.80	1.70	1.62	1.70	1.37	1.22	1.50
H2	T			2.06	2.16	1.95	1.90	2.05	1.57	1.67	1.87
H3	T			1.97	2.33	2.11	2.01	2.17	1.37	1.66	2.02
H4	T	1.79	1.56	0.27	0.95	1.17	1.09	1.08	0.11	0.48	0.61
H5	T	1.55	1.02	0.39	0.83	0.90	0.81	0.80	0.14	0.46	0.56
H6	T	2.36	2.28	1.60	1.78	1.59	1.57	1.63	1.11	1.30	1.48
H7	T	2.48	2.43	1.79	1.82	1.70	1.63	1.70	1.15	1.44	1.60
H8	T	2.01	1.48	0.72	1.15	1.40	1.25	1.27	0.50	0.84	0.95

* T - in tailings; B - in sediment below tailings

TABLE 3. WATERLEVELS, 1986/90

DEPTH of WATER below GROUND, m

Piezom. No.	¥	15-Oct-89 32796	17-Nov-89 32829	04-Dec-89 32846	27-Mar-90 32959	20-Apr-90 32983	03-May-90 32996	12-May-90 33005	16-Jun-90 33040	14-Jul-90 33068	19-Aug-90 33104	12-Oct-90 33158
4	B	3.28	3.36	3.39	3.42	3.11	3.13	3.11	3.14	3.18	3.32	3.36
5A	B	3.41	3.50	3.52	3.64	3.21	3.23			3.28	3.42	
5B	B	1.93	2.11	2.18	2.23	1.93	1.95			1.65	1.84	
7A	T	2.41	2.59	2.66	2.87	2.40	2.42	1.96	1.98	1.96	2.31	2.44
7B	B	2.76	2.89	2.95	3.17	2.51	2.53	2.24	2.26	2.39	2.69	2.76
9	B	3.30	3.44	3.48	3.58	3.19	3.22	2.83	2.84	3.02	3.26	3.35
24A	B	3.42	3.54	3.58	3.68	3.36	3.38	3.00	3.04	3.21	3.40	
24B	B	3.41	3.51	3.55	3.66	3.23	3.23	3.11	3.13	3.26	3.40	
25	B	0.56	0.68	0.72	0.75			0.07	0.09	0.21	0.51	0.57
26	B	0.74	0.70	0.69	0.71	0.53	0.56	0.50	0.51	0.51	0.72	0.65
27A	T	1.71	1.91	2.07	1.97	1.85	1.87	1.93	1.95	1.43	1.92	1.93
27B	T	1.57	1.79	1.80	1.79	1.71	1.73	1.48	1.50	1.23	1.74	1.75
30	B	0.67	0.77	0.85	0.69	0.36	0.37	0.33	0.35	0.49	0.80	0.74
32	B	3.14	3.29	3.31	3.33	2.95	2.97	2.65	2.67	2.81	3.10	3.18
40	B	2.21	2.34	2.48	2.30	2.13	2.15	1.76	1.79	1.88	2.28	2.21
41	B	1.11	0.84	0.93	0.87	0.37	0.38	0.31	0.33	0.35	0.70	0.41
43	B	2.29	2.52	2.57	2.77	2.01	2.03	1.62	1.63	1.82	2.20	2.34
46	B	3.41	3.53	3.58	3.68	3.22	3.23	2.92	2.94	3.07	3.34	3.43
H1	T	1.62	1.76	1.74	1.76	0.75	0.75	0.52	0.55	1.13	1.71	1.62
H2	T	1.97	2.16	2.26	2.31	1.86	1.87	1.24	1.26	1.51	1.96	2.07
H3	T	2.14	2.35	2.22	2.33	1.71	1.75	0.80	0.83	1.40	2.11	2.24
H4	T	0.76	0.91	1.04	0.89	0.10	0.14	0.15	0.17	0.61	1.25	0.85
H5	T		0.77	0.79	0.81	0.20	0.21	0.17	0.19	0.47	0.91	0.67
H6	T	1.59	1.74	1.85	1.91	1.43	1.44	0.89	0.91	1.15		1.63
H7	T	1.70	1.86	1.97	2.01	1.60	1.62	1.08	1.11	1.24	1.67	1.71
H8	T	1.10	1.19	1.20	1.14	0.52	0.58	0.49	0.51	0.88	1.41	

¥ T - in tailings; B - in sediment below tailings

TABLE 3. WATERLEVELS, 1986/90

Piezom. No.	x	DEPTH of WATER below GROUND, m 14-Oct-90 33160	25-Oct-90 33171	1986-1990 MAX.	MIN.	RANGE	UNSATURATED TAILINGS, m MAX.	MIN.	% of TAILINGS UNSATURATED MAX.	MIN.	RANGE
4	B		3.38	3.49	3.05	0.44	3.05	2.90	100%	95%	5%
5A	B	3.48	3.51	3.74	3.19	0.55	1.53	1.53	100%	100%	0%
5B	B	1.97	2.03	2.93	1.65	1.28	1.53	1.50	100%	98%	2%
7A	T		2.53	3.11	1.96	1.15	2.96	1.81	59%	36%	23%
7B	B		2.84	3.42	2.24	1.18	3.27	2.09	65%	42%	23%
9	B	3.34	3.38	3.80	2.83	0.97	3.65	2.68	83%	61%	22%
24A	B	3.52	3.55	3.95	3.00	0.95	1.98	1.98	100%	100%	0%
24B	B	3.49	3.52	3.75	3.09	0.66	1.98	1.98	100%	100%	0%
25	B		0.65	1.12	0.07	1.05	0.97	0.00	49%	0%	49%
26	B		0.69	1.07	0.50	0.57	0.92	0.35	32%	12%	20%
27A	T		2.14	2.70	1.30	1.40	2.55	1.15	51%	23%	28%
27B	T		1.92	2.56	1.02	1.54	2.41	0.87	55%	20%	35%
30	B		0.80	1.37	0.32	1.05	1.22	0.17	53%	7%	46%
32	B		3.23	3.70	2.65	1.05	2.59	2.50	100%	96%	4%
40	B		2.37	2.90	1.76	1.14	2.75	1.61	67%	39%	28%
41	B		0.61	1.61	0.31	1.30	1.46	0.16	42%	5%	37%
43	B		2.41	3.13	1.62	1.51	2.98	1.47	67%	33%	34%
46	B		3.48	3.93	2.92	1.01	3.78	2.77	85%	63%	23%
H1	T		1.79	1.96	0.52	1.44	1.81	0.37	93%	19%	74%
H2	T		3.18	3.18	1.24	1.94	2.70	1.09	100%	40%	60%
H3	T		2.42	2.78	0.80	1.98	2.63	0.65	96%	24%	72%
H4	T		0.97	1.79	0.10	1.69	1.64	0.00	79%	0%	79%
H5	T		0.77	1.55	0.14	1.41	1.40	0.00	62%	0%	62%
H6	T		1.72	2.36	0.89	1.47	2.21	0.74	94%	31%	62%
H7	T		1.82	2.48	1.08	1.40	2.33	0.93	85%	34%	51%
H8	T	1.03	1.20	2.01	0.49	1.52	1.86	0.34	88%	16%	72%

x T - in tailings; B - in sediment below tailings

TABLE 4. SUBSURFACE TEMPERATURES 1986/90

TEMPERATURES (degrees C) from THERMISTOR STRING in TAILINGS

LOCATION: Northing 16175
Easting 10965

DEPTH, cm	0.00	10.16	22.86	38.10	60.96	91.44	121.92	152.40	182.88	213.36	243.84
31/10/86	-2.5	4.0	6.4	6.4	8.3	9.9	10.8	13.1	13.1	13.6	13.3
03/11/86	-5.2	-3.2	1.7	4.3	7.1	8.8	10.3	12.2	12.1	12.7	13.2
04/11/86	-4.1	-3.8	-1.3	2.5	6.5	8.6	9.4	10.8	11.7	12.3	12.6
05/11/86	2.1	1.5	1.1	2.4	5.3	7.2	9.4	10.1	11.7	12.6	12.3
17/11/86	-1.5	1.6	2.2	3.8	4.8	7.6	7.7	9.1	11.2	11.6	12.7
22/11/86	1.3	2.1	1.8	3.5	4.6	6.3	8.3	8.4	10.6	11.6	12.3
30/11/86	0.6	1.9	3.1	4.7	6.0	6.8	8.0	8.6	10.0	11.1	11.6
07/12/86	0.0	1.9	3.1	4.2	5.4	6.8	7.7	7.7	10.0	10.5	11.0
14/12/86	2.0	3.2	4.3	5.2	6.3	7.2	7.4	9.3	9.0	10.9	12.0
21/12/86	1.5	1.8	2.6	4.1	5.2	6.1	6.5	7.4	8.6	9.0	9.8
28/12/86	1.3	2.0	2.5	3.7	5.1	5.8	6.3	7.4	8.5	9.0	9.2
04/01/87	0.6	1.0	1.7	2.8	3.9	5.5	6.0	7.3	7.8	8.2	8.6
11/01/87	1.3	1.6	2.5	3.5	4.6	5.5	6.4	6.8	7.8	8.3	8.8
24/01/87	-5.4	-4.5	1.8	1.7	3.8	5.1	6.7	7.1	8.1	10.2	10.7
08/02/87	-0.8	0.6	1.0	1.9	3.5	4.0	5.0	6.1	7.0	7.6	8.3
15/02/87	0.8	1.5	2.6	3.5	4.3	5.2	6.3	7.2	8.3	8.5	8.7
22/02/87	0.3	1.1	1.0	1.8	2.6	3.7	4.5	4.5	5.4	6.0	7.0
01/03/87	0.3	1.8	2.5	3.2	3.3	3.4	3.8	4.3	5.1	5.8	6.4
15/03/87	2.3	1.3	1.2	1.8	3.5	4.7	5.3	5.6	6.5	7.2	7.6
29/03/87	0.3	1.3	2.1	3.8	4.6	5.0	5.1	6.0	6.8	7.0	7.7
10/04/87	14.5	10.5	8.9	8.6	6.8	5.0	4.2	4.8	4.9	5.6	5.8
15/04/87	19.0	13.2	10.0	8.2	7.1	6.1	5.5	4.7	4.5	4.4	4.8
29/04/87	17.3	13.3	11.7	11.5	11.3	10.5	9.6	9.1	8.3	8.0	8.1
06/05/87	17.6	17.1	15.4	15.3	14.6	12.1	10.6	10.0	8.8	7.9	7.8
14/05/87	12.0	12.5	13.7	15.3	15.8	14.2	13.0	12.1	10.5	9.7	9.1
23/05/87	17.8	14.5	12.3	12.7	13.2	12.9	12.9	12.5	11.3	10.5	9.6
01/06/87	23.0	20.3	18.1	17.0	17.1	16.4	15.3	13.8	12.1	11.0	10.2
14/06/87	26.3	23.7	22.2	21.7	20.0	17.3	16.0	15.3	13.3	12.2	11.0
20/06/87	32.5	29.1	26.0	24.6	22.7	20.1	17.4	15.8	13.1	11.8	10.7
28/06/87	24.3	25.3	23.9	22.6	22.2	21.4	20.0	18.6	16.0	14.2	12.8
05/07/87	29.5	27.1	24.4	23.6	22.0	19.7	18.2	17.2	15.3	14.1	12.7
18/07/87	22.1	24.0	23.5	22.8	22.1	20.5	19.3	18.6	17.1	15.9	14.8
15/08/87	31.2	30.4	26.2	24.2	23.1	22.0	21.3	20.8	19.3	18.3	17.4
25/09/87	14.7	12.6	13.6	16.3	18.4	18.7	18.8	18.5	17.8	17.2	17.4
06/10/87	6.3	7.3	9.0	11.3	14.6	16.3	17.0	17.7	17.3	17.9	17.3
12/11/87	-0.2	3.6	3.9	5.1	6.7	7.8	12.5	9.8	11.7	12.3	13.7
14/12/87	-3.8	1.1	1.9	3.2	4.7	6.0	8.6	7.8	9.1	9.9	10.8
17/01/88	-4.7	-0.6	0.2	1.3	3.1	5.1	7.0	7.6	9.1	10.1	10.7
14/04/88	1.3	2.4	2.6	3.0	3.7	3.9	4.0	4.4	5.0	5.5	6.0
25/04/88	7.5	5.7	5.7	6.6	6.1	5.5	4.8	4.6	4.8	5.1	5.8
16/06/88	22.7	22.1	21.8	22.9	23.5	23.0	22.3	21.5	19.5	18.7	17.7
10/06/89	26.3	27.6	24.7	21.1	18.0	15.8	14.3	13.3	11.7	10.8	9.8
24/06/89	31.7	22.8	20.7	20.1	20.0	19.0	17.5	16.3	14.2	12.8	11.7
08/07/89	30.4	29.2	26.5	24.6	23.6	22.3	20.6	19.0	16.9	15.1	13.9
22/07/89	38.1	32.6	29.8	27.8	25.8	23.4	21.3	19.8	17.5	16.0	14.6
26/08/89	24.1	24.0	23.3	23.3	23.1	22.0	21.0	20.2	18.9	17.9	17.0
09/09/89	16.5	15.7	16.2	17.5	19.5	20.2	20.3	20.1	19.2	18.2	17.7
23/09/89	12.7	9.9	9.6	11.5	15.2	18.1	18.2	18.1	18.0	17.5	16.8

TABLE 4. SUBSURFACE TEMPERATURES 1986/90

TEMPERATURES (degrees C) from THERMISTOR STRING in TAILINGS

LOCATION: Northing 16175
Easting 10965

DEPTH, cm	0.00	10.16	22.86	38.10	60.96	91.44	121.92	152.40	182.88	213.36	243.84
07/10/89	9.7	7.5	6.8	8.1	10.7	13.1	14.8	15.0	15.5	15.8	15.7
15/10/89	2.5	4.5	6.1	8.1	10.8	12.4	13.1	13.7	14.7	15.1	15.3
17/11/89	-8.8	-2.5	0.8	4.0	7.0	9.0	10.3	11.3	13.0	13.6	14.0
04/12/89	-3.8	-3.7	-3.0	-1.1	2.0	4.9	6.2	7.1	8.8	9.8	10.5
27/03/90	2.6	-0.5	-2.2	-1.0	1.9	3.7	4.2	4.8	6.0	6.5	7.3
20/04/90	18.5	13.2	9.2	5.0	4.4	4.1	3.8	3.1	4.6	5.1	5.7
03/05/90	15.2	9.8	7.1	5.6	5.6	6.1	6.3	6.5	6.1	6.3	6.4
12/05/90	12.5	10.9	9.4	7.6	7.2	7.2	7.1	6.8	6.8	6.6	6.5
16/06/90	31.5	26.3	23.2	20.2	17.9	16.6	15.2	14.4	12.2	11.5	10.3
14/07/90	28.8	25.8	24.5	24.3	23.1	20.7	18.6	17.3	15.5	14.3	13.2
19/08/90	23.8	21.6	20.5	20.5	21.5	21.3	20.5	19.7	18.2	17.0	16.0
14/10/90	10.1	7.8	7.0	8.5	10.6	12.1	13.0	13.6	14.0	14.6	14.8
25/10/90	7.8	6.2	6.0	7.1	9.7	11.6	12.8	13.7	14.9	15.5	15.8
MAX	38.1	32.6	29.8	27.8	25.8	23.4	22.3	21.5	19.5	18.7	17.7
MIN	-8.8	-4.5	-3.0	-1.1	1.9	3.4	3.8	3.1	4.5	4.4	4.8
RANGE	46.9	37.1	32.8	28.9	23.9	20.0	18.5	18.4	15.0	14.3	12.9

SOUTH BAY FIELD DATA - OCTOBER 1990

PIEZOMETERS:			TOP						BOTTOM					
Date & Source		*	Temp. C	Cond.	pH units	Eh mV	Eh (corr.	pE units	Temp. C	Cond.	pH units	Eh mV	Eh (corr.	pE units
12/10/90	H4	T	8.0	1250	5.29	-108	144	2.48	8.0	900	5.5	-97	155	2.67
Repeat	H4	T	7.0	1300	5.67	-53	200	3.44	6.0	1300	5.8	-50	204	3.50
12/10/90	M4	B	10.0	6000	4.54	150	401	6.89	9.5	6000	4.8	78	329	5.66
12/10/90	M7A	T	10.0	6000	2.67	267	518	8.90	9.0	6000	3.4	241	493	8.47
12/10/90	M7B	B	9.0	7000	5.52	-95	157	2.69	9.0	7000	5.5	-92	160	2.74
Post-bail	M7B	B	6.0	8000	5.75	-104	150	2.57						
12/10/90	M9	B	8.0	3700	2.80	330	582	10.01						
13/10/90	M10	O	6.5	7000	2.14	510	763	13.12	6.5	7000	2.2	493	746	12.83
Post-bail	M10	O	6.5	7000	2.08	510	763	13.12						
11/10/90	M24A	B	9.5	3200	3.31	218	469	8.07	9.0	4700	4.2	145	397	6.82
11/10/90	M24B	B	9.0	1150	2.72	416	668	11.48	7.5	3920	3.0	270	523	8.98
12/10/90	M25	B		2000	5.45	-108	150	2.57	5.0	700	5.8	-63	191	3.29
12/10/90	M26	B	8.0	2000	5.66	-58	194	3.34	8.0	2000	6.1	-113	139	2.39
11/10/90	M27A	T	9.5	2200	5.93	-36	215	3.70	9.5	2200	6.7	-92	159	2.74
Repeat	M27A	T	6.0	2500	5.74	-60	194	3.33	7.5	2200	6.0	-54	199	3.41
11/10/90	M27B	T	10.0	2020	6.45	14	265	4.55	9.0	2050	6.6	-75	177	3.04
Repeat	M27B	T	6.0	2250	5.73	25	279	4.79	7.0	2200	5.7	-20	233	4.00
12/10/90	M30	B	7.0	170	5.55	11	264	4.54	7.0	170	7.3	100	353	6.07
Repeat	M30	B	7.0	300	5.87	13	266	4.57	6.0	300	6.1	59	313	5.37
12/10/90	M40	B	12.0	3300	4.37	247	497	8.54	9.0	3300	5.4	25	277	4.75
12/10/90	M41	B	8.5	1100	6.17	-117	135	2.32	8.5	1050	5.9	-146	106	1.82
12/10/90	M47	O	8.0	4000	3.83	286	538	9.25	7.5	3500	5.2	-61	192	3.29
13/10/90	M55	O	18.0	120	5.71	48	294	5.05						
13/10/90	M56	O	14.0	300	6.02	13	261	4.49						

* LOCATED: T - in tailings; B - below tailings; O - outside tailings area

SURFACE WATERS:		Temp. C	Cond.	pH units	Eh mV	Eh (corr.	pE units
Mill Pond Dam	MP	6.0	2400	3.66	354	608	10.44
Polishing Pond	PP	6.0	350	6.20	145	399	6.85
Chara Pond	CP	15.0	850	6.42	40	288	4.94
Decant Beach	DPB	T 15.0	700	5.50	-33	215	3.69
Decant Outflow	DPO	15.0	500	6.36	74	322	5.53
Mud Lk. Outfl.	C11	13.0	150	5.75	3	252	4.33

NUMBER		M4	M4	M4 Top	M4 Bottom	M7B	M7B	M7B	M7B Top	M7B Bottom
Day/Mo/Yr		06/11/86	12/04/88	11/10/90	11/10/90	06/11/86	19/07/87	12/04/88	11/10/90	11/10/90
Temp., C		6.5		10	9.5	7.5			9	9
pH, fld.		5.8	4.68	4.54	4.76	6.3	5.9	5.15	5.52	5.45
pH, lab.		4.55	3.82	5.45	5.65	5.7		4.61		
Cond., fld.		2850		6000	6000	6000	10400		7000	7000
Cond., lab.			2200	1000	1350			8000		
Eh, mV				150	78				-95	-92
Acidity		3958				9460				
Alkalinity										
Elements:	At.Weights									
Ag	107.8680							0.02		
Al	26.9815	1.7	5		0.9	1.4	3.5	5.3		
As	74.9216	3.3	0.05			4	0.4	0.08		
B	10.8100	0.59	1	0.06	0.05	2.7	2.3	6		
Ba	137.3300		0.03					0.04		0.01
Be	9.0122					0.02	0.05	0.01		
Bi	208.9804	0.57	0.1			1.5	0.6	0.2		
C	12.0110	408	1275			1717	3937	150		
Ca	40.0800	452	364	127	126	529	482	169	229	217
Cd	112.4100	0.08	0.06			0.18	0.07	0.1	0.1	0.1
Ce	140.1200	0.26	0.06			0.42	0.2	0.02		
Co	58.9332	0.51	0.5			0.76	1.8	1.1	0.6	0.6
Cr	51.9960	0.13	0.1			0.3	0.3	0.3	0.01	0.01
Cu	63.5460		0.05			0.005	0.2	0.2		
Fe	55.8470	1009	644	40	37	3643		6810	2219	2186
Hg	200.5900	0.64				1.3	0.2	0.09		
K	39.0983	31	28	3.7	3.3	36	71	24	1.2	0.9
La	138.9055	0.13	0.02			0.1	0.05	0.1		
Mg	24.3050	163	189	24	23	364	532	189	175	175
Mn	54.9380	35	23	1.5	1.5	128	194	100	59	56
Mo	95.9400		0.1			0.53	0.1	0.7		
Na	22.9898	15	22	38	69	32	42	3	15	15
Nb	92.9064	0.28	0.04			1	0.3	0.6		
Ni	58.7000	0.26	0.2			0.45	1.2	0.9	0.2	0.2
P	30.9738	0.8				3.8	1.2	7	3.3	3.3
Pb	207.2000	0.86	0.4			1.9	2	1.9	0.4	0.3
S	32.0600	1233	1249	205	204	2459	5193	2969	2432	2436
Sb	121.7500	0.9	0.09			2	0.2	0.4		
Se	78.9600	2.1	0.07			5.5	0.1	0.3		
Si	28.0855	11	12	0.2	0.08	12	19	9	6.1	5.9
Sn	118.6900	0.5				1.1	0.2	0.05		
Sr	87.6200	0.67	0.9	1.2	1.3	0.93	1.1	4	1.8	1.8
Te	127.6000	1.2	0.1			2.8	0.08	5	0.01	0.01
Th	232.0381	0.66	0.6			2	1.1	4		
Ti	47.9000	0.04	0.02	0.1		0.04		0.2		
U	238.0290	2.4	4			10	5.8	21	0.01	0.01
V	50.9415	0.05	0.03			0.1	0.2	0.06		
W	183.8500	1.8	0.1			3.3	0.8	0.8	0.02	0.02
Y	88.9059	0.04	0.08			0.04	0.04	0.1		
Zn	65.3800	60	45	1.1	1.8	91	267	345	118	115
Zr	91.2200	0.05	0.05			0.1	0.4	0.1		
CHLORIDE	35.453			14	14				18	15
Eh, corr.				401	329				157	160
pE				6.79	5.58				2.65	2.70
Sum Cations		94.91	72.78	12.33	13.48	261.96	87.10	405.35	151.47	148.89
Sum Anions		76.92	77.92	13.18	13.12	153.40	323.96	185.22	152.22	152.39
% Error		10%	-3%	-3%	1%	26%	-58%	37%	-0%	-1%

NUMBER	M78-Top postbail	M10	M10 prebail	M10 postbail	M10 prebail	M10 postbail	M10-Top prebail	M10-Top postbail	M10-Bot prebail	M25
Day/Mo/Yr	11/10/90	19/07/87	12/04/88	12/04/88	15/10/89	15/10/89	11/10/90	11/10/90	11/10/90	06/11/86
Temp., C	5				6		6.5	17	6.5	7.5
pH, fld.	5.75	2.3	2.29	2.26	2.31		2.14	2.08	2.2	6.8
pH, lab.	5.48		2.14	2.11			1.99	1.89	2.1	6.55
Cond., fld.	8000	8500			6100		7000	5000	7000	410
Cond., lab.	8000		7000	6000			6500	7000	7000	
Eh, mV	-104						510	464	493	
Acidity										63.7
Alkalinity										
Elements:										
Ag			0.03	0.02	0.08					0.01
Al		3	505	340	520	502	196	208	212	0.33
As		0.1			0.03	0.03				1.1
B	3.1	0.005	8	7	0.8	0.7	2.3	2.2	2.6	0.04
Ba	0.02		0.04	0.03	0.05	0.05				0.13
Be	0.01	0.04	0.03	0.02						
Bi	0.06	0.7	0.3	0.3	0.03	0.03	0.05	0.04	0.06	0.03
C		1135	648	183	1970	700				1413
Ca	249	468	378	266	480	466	226	240	250	98
Cd	0.2	1.4	1.8	2	0.02	0.01	0.5	0.5	0.6	0.02
Ce		1.2	0.6	0.2	0.07	0.07	0.07	0.1	0.1	0.1
Co	0.8	6.8	7	5	0.06	0.06	2.1	2.1	2.4	0.008
Cr	0.05	1.2	1	1	1.6	1.5	0.4	0.4	0.4	0.02
Cu	0.09	56	64	54	45	51	27	30	34	0.04
Fe	2731		6338	4311	7400	6830	2028	1929	2306	1
Hg		0.3	0.1	0.1						
K	0.2	44	3	1						17
La		0.4	0.3	0.09	0.03	0.03	0.6	1.1	0.8	0.03
Mg	195	224	238	189	239	229	76	74	79	19
Mn	68	26	25	18	23	22	6.3	7.1	7.7	0.59
Mo	0.02	1.7	1	1	0.1	0.1	0.02	0.02	0.03	
Na	16	10	5	4	3.9	4.8	2.1	2.5	1.9	24
Nb	0.05	0.2	0.1	0.09	0.01	0.01			0.01	0.04
Ni	0.2	2.1	1	1	2	6.5	0.8	4.3	0.5	0.07
P	3.8	5.7	32	23	6.3	5.9	11	11	13	0.09
Pb	0.5	3.5	3	2	3.2	3.1	0.5	0.5	0.6	0.12
S	2915	6259	6850	5680	6660	6200	3030	2931	3305	32
Sb		0.3	0.9	0.7	0.1	0.1				0.16
Se	0.02	1.3	0.6	0.4	0.1	0.1				
Si	6.6	94	72	57	102	100	39	36	32	8.3
Sn		0.2	0.1		0.01	0.01				
Sr	2.1	0.1	0.4	0.3	0.1	0.1	0.5	0.5	0.7	0.1
Te	0.01	1	0.6	0.6	0.07	0.06	0.01	0.01	0.01	0.12
Th		1	1	0.5	0.06	0.05	0.01	0.01	0.01	0.12
Ti		0.2	0.6	0.7	0.5	0.5	0.2	0.1	0.1	0.01
U		4.7	6	2	0.3	0.3	0.01	0.01	0.01	0.71
V		0.4	0.3	0.2	0.2	0.1				0.01
W	0.02	1	0.8	0.9	0.06	0.06	0.02	0.02	0.02	0.13
Y		1.2	1	0.6	0.1	0.1	0.3	0.4	0.3	0.01
Zn	115	293	274	35	168	164	75	76	88	0.78
Zr	0.02	0.5	0.3	0.2	0.4	0.4	0.04	0.04	0.06	0.03
CHLORIDE	25						15	15	8	
Eh, corr.	150						763	710	746	
pE	2.55						12.94	12.04	12.65	
Sum Cations	181.87	60.36	451.79	307.33	511.41	1472.44	158.97	156.77	176.86	8.07
Sum Anions	182.55	390.46	427.32	354.34	415.47	386.77	189.44	183.27	206.40	2.00
% Error	-0%	-73%	3%	-7%	10%	58%	-9%	-8%	-8%	60%

NUMBER	M25 Top	M25 Bottom	M27A	M27A	M27A Top	M27A Bottom	M27B	M27B	M27B Top	M27B Bottom
Day/Mo/Yr	11/10/90	11/10/90	06/11/86	12/04/88	11/10/90	11/10/90	06/11/86	12/04/88	11/10/90	11/10/90
Temp., C	5	5	7		9.5	9.5	7		6	7
pH, fld.	5.45	5.77	7.1	6.63	5.93	6.72	6.6	5.84	5.73	5.7
pH, lab.	5.95	6.01	7.05	6.28	5.7	5.85	6.1	6.2	5.35	5.45
Cond., fld.	2000	700	350		2200	2200	950		2250	2200
Cond., lab.	500	800		700	2100	1600		1300	2350	1900
Eh, mV	-108	-63			-36	-92			25	-20
Acidity			17.3				57.9			
Alkalinity										
Elements:										
Ag			0.01				0.02			
Al			0.35	0.4			0.44	0.4		
As			1	0.03			1.3	0.04		
B	0.08		0.01	0.1	0.1	0.05	0.05	0.1	0.1	
Ba	0.1	0.1		0.04	0.05	0.05		0.05	0.01	
Be		0.01	0.007					0.01		
Bi			0.02	0.04				0.07		
C			681	847			365	323		
Ca	73	61	65	150	240	241	189	332	236	233
Cd			0.02	0.01			0.02	0.03		
Ce			0.16				0.12	0.01		
Co			0.03	0.09			0.02	0.1		
Cr			0.01	0.03			0.03	0.05		
Cu			0.05	0.02			0.07	0.05		
Fe	66	5.2	0.44	12	47	29	16	2.6	0.4	0.1
Hg										
K			22	32	13	13	26	42	9.8	9.3
La			0.01				0.03			
Mg	20	15	3.4	19	79	79	16	76	96	97
Mn	2.4	0.2	0.42	1.7	2.1	1.2	1.6	0.8	0.4	0.3
Mo			0.04							
Na	18	17	43	70	49	49	38	73	48	48
Nb			0.06				0.08			
Ni			0.05	0.02			0.07	0.04		
P			0.05				0.06			
Pb			0.19	0.1			0.27	0.1		
S	102	36	44	211	382	369	181	542	381	680
Sb			0.25				0.3			
Se							0.16			
Si	4.7	4.2	3.7		1.2	1.1	3.5	0.7	0.4	0.3
Sn							0.012			
Sr	0.3	0.3	0.08	1.4	1.7	1.7	0.22	1	1.7	1.8
Te			0.11				0.12			
Th			0.09				0.14			
Ti			0.01	0.01			0.02	0.01		
U			0.81	0.5			1	1	0.01	
V			0.02	0.02			0.03	3		
W			0.13				0.2			
Y			0.01				0.01			
Zn	4.9	0.1	0.39	1.9	2.1	0.1	3.9	4	0.4	0.4
Zr			0.02	0.02			0.03	0.03		
CHLORIDE	6	5			9	8			5	12
Eh, corr.	146	191			215	159			279	233
pE	2.48	3.24			3.65	2.70			4.72	3.95
Sum Cations	9.86	5.31	6.05	13.72	23.61	22.60	14.15	27.41	22.06	21.96
Sum Anions	6.53	2.39	2.74	13.16	24.08	23.24	11.29	33.81	23.91	42.76
% Error	20%	38%	38%	2%	-1%	-1%	11%	-10%	-4%	-32%

NUMBER A36 M30	M30	M30 Top	M30 Bottom	M47	M47	M47	M47 Top	M47 Bottom	M55
Day/Mo/Yr	06/11/86	12/04/88	11/10/90	11/10/90	06/11/86	19/07/87	12/04/88	11/10/90	11/10/90	19/07/87
Temp., C	6		7	6	8			8	7.5	
pH, fld.	6.6	6.61	5.87	6.08	6.2	5/5.2	6.05	3.83	5.23	6
pH, lab.	6.55	6.65	6.01	6.1	5.8		5.57	5.12	5.3	
Cond., fld.	115		300	300	2400	3080		4000	3300	111
Cond., lab.		160	400	300			3150	3750	3500	
Eh, mV			13	59				286	-61	
Acidity	13.5				1988					
Alkalinity									170	
Elements:										
Ag	0.03									
Al	0.44	0.3			0.55	3.2	0.6			3.3
As	0.77				2.7	0.2	0.06			0.1
B	0.01	0.1			0.27	0.2	2	0.8	1.1	
Ba		0.02					0.04	0.01	0.01	
Be										
Bi	0.05				0.21	0.2	0.1			0.2
C	283	113			990	740	1413			138
Ca	28	36	21	21	381	480	669	270	285	67
Cd	0.02				0.03		0.09	0.01	0.04	
Ce	0.13					0.4	0.02			0.4
Co	0.03				0.44	0.6	1	0.3	0.4	
Cr	0.03				0.09	0.01	0.1			
Cu	0.03					0.4	0.05			0.2
Fe	0.36	21	0.3	0.02	580		752	470	615	74
Hg					0.13		0.03			0.01
K	13	6			18	74	26			67
La	0.07				0.03	0.08	0.1			0.09
Mg	3.4	6.1	2.1	1.8	105	133	174	75	89	19
Mn	0.47	0.8	0.09	0.04	29	33	45	24	29	4.4
Mo	0.02					0.1	0.4			
Na	6.6	5	2.9	2.5	22	33	32	18	20	16
Nb	0.07				0.18	0.1	0.06			0.1
Ni	0.07	0.07			0.11	0.7	0.6	0.09	0.06	0.3
P	0.07	0.1			0.64	0.7		0.7	1.1	0.4
Pb	0.28	0.01			0.39	0.4	0.5		0.04	0.2
S	12	56	21	20	802	1285	1947	766	914	164
Sb	0.2				0.3	0.03	0.1			0.09
Se	0.19				1.4	0.3	0.1			0.2
Si	6.3	6	3.1	3.3	11	12	15	5.5	6.3	12
Sn					0.15	0.07	0.02			0.04
Sr	0.05	0.1	0.1	0.1	0.44	0.4	1	1.3	1.4	
Te	0.11				1	0.4	0.2	0.03	0.05	0.3
Th	0.13				0.34	0.3	0.9	0.02	0.04	0.2
Ti	0.02				0.01	0.01	0.02			
U	1				1	1.7	7	0.02	0.04	0.2
V	0.03	0.01			0.03	0.2	0.04			0.2
W	0.14				2.2	0.4	0.4			0.1
Y	0.01				0.01	0.04	0.02			0.04
Zn	0.33	2.7	0.2	0.09	0.86	143	219	61	73	19
Zr	0.03				0.02	0.3	0.07			0.3
CHLORIDE			3	1				5	3	
Eh, corr.			266	313				538	192	
pE			4.51	5.30				9.12	3.25	
Sum Cations	2.39	3.94	1.37	1.31	61.37	44.18	98.56	48.56	58.75	12.41
Sum Anions	0.75	3.49	1.39	1.28	50.03	80.16	121.46	47.93	57.10	10.23
% Error	52%	6%	-1%	1%	10%	-29%	-10%	1%	1%	10%

NUMBER	MS5	MS5	MS6	MS6 total	MS6 filtered	MS6	MS6	MS6	MS6	MS6
Day/Mo/Yr	15/10/89	11/10/90	02/04/87	27/04/87	27/04/87	19/07/87	23/05/88	23/06/88	15/10/89	11/10/90
Temp., C	6	18					18		6	14
pH, fld.	5.4	5.71	7.66	7.66	7.66	6.6	7.2		6.25	6.02
pH, lab.		6.01								6.2
Cond., fld.	110	120	280	280	280	255	200		165	300
Cond., lab.		200								550
Eh, mV		48								13
Acidity										
Alkalinity		250								310
Elements:										
Ag			0.03							
Al	0.06		0.7	31	0.2	2.1	0.3	0.1	0.3	
As			3.5	1.8	1.4	1.1	0.2			
B	0.04						0.01		0.04	
Ba	0.03		0.03	0.3	0.01		0.01	0.01	0.05	
Be			0.06		0.005					
Bi				0.1		0.1	0.3			
C	344		5.6	1642	1924	354	543	1564	557	
Ca	11	5.5	110	114	57	66	43	44	55	28
Cd			0.03							
Ce			0.11	0.2	0.03	0.3	0.05			
Co				0.07	0.07		0.06	0.01		
Cr				0.1	0.01		0.01			
Cu	0.01		0.02	0.36		0.3	0.03		0.03	
Fe	0.7	0.9	12.7	42			0.3	0.2	1.2	0.4
Hg					0.4		0.1			
K	0.9		10	3	2	59	1		2.9	
La			0.03	0.1	0.008	0.08				
Mg	2.8	0.8	13	31	6.6	9.9	5.3	5	6.6	3.4
Mn	0.1	0.03	0.7	1	0.24	0.12	0.1	0.1	0.2	0.1
Mo			0.06		0.4		0.04			
Na	5.7	3.1	7.3	5	5	23	3.1	3	5.6	2.9
Nb			0.08	0.08	0.04	0.01	0.03			
Ni	0.02		0.18	0.09		0.3				
P	0.01		2.7	4.8	0.5	0.3	1.5	0.1	0.1	
Pb	0.01			0.4	0.05	0.1	0.06			
S	4.8	2.5	15.9	5	4	6	5	39	2.7	3.4
Sb			0.07	0.4		0.8	0.03			
Se			0.4	1.1	0.9	0.2	0.1			
Si	14	5.2	138	786	166	8.8	6.4	5	7.7	3.3
Sn					0.03	0.3				
Sr	0.02	0.03	0.2	0.2	0.1		0.09	0.08	0.05	0.09
Te		0.01	0.6	0.1	0.08	0.2	0.1			
Th			0.07	0.2	0.04	0.1	0.04			
Ti			0.03	0.3	0.02	0.02	0.02	0.01	0.01	
U			0.5	0.8	0.4	1.9	0.3		0.04	
V			0.05	0.1	0.01	0.2				
W			0.3	0.03		0.1	0.06			
Y			0.01	0.08		0.04				
Zn	0.1	0.06	3	1.5			0.07		0.1	0.4
Zr			0.19	0.1	0.09	0.2				
CHLORIDE		8								81
Eh, corr.		294								261
pE		4.98								4.43
Sum Cations	1.11	0.53	8.01	14.33	3.69	6.87	2.80	1002.76	3.72	1.84
Sum Anions	0.30	0.38	0.99	0.31	0.25	0.37	0.31	2.43	0.17	2.50
% Error	57%	16%	78%	96%	87%	90%	80%	100%	91%	-15%

NUMBER	Dec.Pond Beach	Dec.Pond Outflow	Milt's Wild Rice	Mill Pond By Dam	Dave's Dam	Chara Pond	Polishing Pond(M20)	Boomerang Landing	Boomerang Outflow	Mud L(C11) Outflow
Day/Mo/Yr	11/10/90	11/10/90	11/10/90	11/10/90	11/10/90	11/10/90	11/10/90	11/10/90	11/10/90	11/10/90
Temp., C	15	15		6		15	6		20	13
pH, fld.	5.5	6.36	5.36	3.66	3.79	6.42	6.2	6.15	6.63	5.75
pH, lab.		6.45	5.55	3.3	3.91		7.05	6.3	6.41	6.44
Cond., fld.	700	500		2400		850	350		200	150
Cond., lab.		500	150	2400	600		450	500	200	150
Eh, mV	-33	74		354		40	145			3
Acidity										
Alkalinity										400
Elements:										
Ag										
Al				3.9	1.2			0.3		0.01
As										
B										
Ba								0.01		0.01
Be										0.01
Bi										0.01
C										
Ca	99	96	4.8	248	54	108	36	36	5.1	6.5
Cd				0.7						
Ce										
Co				0.1						
Cr										
Cu				19	1.1					
Fe	3.3	0.1	0.6	48	0.4	0.3	0.02	0.8	0.1	0.1
Hg										
K										
La										
Mg	12	10	0.1	52	8.6	14	4.9	6.6	0.09	0.1
Mn	0.2		0.01	11	2.2	0.03	0.02	3.8	0.05	
Mo										
Na	3.7	2.6	0.2	2.3	1.1	4.1	3.8	1.9		0.3
Nb										
Ni										
P				0.1						
Pb										
S	106	87	2.1	462	89	96	34	56	2.1	1.1
Sb										
Se										
Si	0.5	0.1		6.1	4.4	0.4	0.2	3.2		
Sn										
Sr	0.4	0.3		0.8	0.2	0.5	0.2	0.1		
Te										
Th										
Ti										
U										
V										
W				0.03	0.04					
Y				0.01						
Zn	2.2	0.5	0.1	175	38	0.1	0.08	5.2	0.3	0.05
Zr										
CHLORIDE				2			8	1	10	9
Eh, corr.	215	322		608		288	399			252
pE	3.64	5.45		10.30		4.87	6.75			4.27
Sum Cations	6.34	5.75	0.30	26.34	5.04	6.74	2.37	2.80	0.28	0.36
Sum Anions	6.61	5.43	0.13	28.88	5.55	5.99	2.35	3.52	0.41	0.32
% Error	-2%	3%	39%	-5%	-5%	6%	0%	-11%	-19%	5%

LOG[IAP/KT] values from "PHREEQE" for OCTOBER 1990 ANALYSES:

SAMPLE #	1	2	3	4	5	6	7	8	9	10
SOURCE	M10 PREBAIL	M10 POSTBAIL	M10 BOTTOM	M47 TOP	M47 BOTTOM	M7B TOP	M7B BOTTOM	M7B BAILED	M25 TOP	M25 BOTTOM
MISSING DATA:										
Alkalinity						xxxxx	xxxxx	xxxxx	xxxxx	xxxxx
Chloride										
Redox Potential										
Temperature										
BALANCES:										
% Error	-9.00%	-8.00%	-8.00%	1.00%	1.00%	0.00%	-1.00%	0.00%	20.00%	38.00%
PHR Electrical	-2.680%	-2.500%	-3.050%	-0.771%	-1.290%	-4.100%	-4.320%	-5.040%	0.214%	0.283%
MINERALS:										
Al(OH)SO4	-0.231	-0.321	-0.147							
Al4SO4(OH)10										
Alunite										
Boehmite										
Diaspore										
Gibbsite										
Chalcedonite	0.577	0.412	0.493	-0.306	-0.237	-0.258	-0.273	-0.166	-0.343	-0.393
Cristobalite	0.690	0.500	0.607	-0.196	-0.127	-0.151	-0.166	-0.050	-0.226	-0.276
Quartz	1.145	0.935	1.062	0.256	0.326	0.299	0.284	0.408	0.232	0.182
Fe(OH)3	0.166	-0.241	0.322	1.889	0.287	1.006	0.839	1.554	-0.571	0.124
Fe(OH)2.7	4.182	3.792	4.236	5.266	3.176	4.030	3.860	4.549	2.358	2.937
Goethite	1.635	1.637	1.790	3.418	1.796	2.575	2.408	2.962	0.836	1.531
Hematite	8.179	8.236	8.490	11.751	8.507	10.072	9.738	10.824	6.573	7.962
Jarosite	5.517	6.060	5.804	3.727						
Lepidocrocite	1.467	1.059	1.623	3.183	1.588	2.307	2.140	2.855	0.729	1.424
Maghemite	-0.715		-0.404	2.729	-0.473	0.964	0.630	2.060		-0.802
Magnetite	0.765	1.644	1.460	8.223	7.840	10.466	9.984	11.538	5.527	6.529
Mg-ferrite										
Gypsum	0.035	0.021	0.091	0.027	0.067	0.080	0.059	0.148	-0.906	
Celestite				-0.8746	-0.818	-0.5336	-0.5291	-0.4354		
Cu metal								0.470		
Cuprite								0.084		
Cuprous-ferrite	-0.643	-0.026	-0.057					12.047		
Cupric-ferrite								5.296		
ZnSiO3					-0.861	-0.226	-0.396	0.019		
Anglesite	-0.667	-0.734	-0.586			-0.774	-0.898	-0.653		
Na-nontronite	8.788	7.786	8.853							
K-nontronite										
Ca-nontronite	16.076	15.051	16.161							
Mg-nontronite	15.739	14.709	15.820							
Chlorite-Fe										
Montmorillonite										

Blanks represent values < -1.000

LOG[IAP/KT] values from "PHREEQE" for OCTOBER 1990 ANALYSES:

SAMPLE #	11	12	13	14	15	16	17	18	19	20
SOURCE	DECANT BEACH	DECANT OUTFLOW	M30 TOP	M30 BOTTOM	M4 TOP	M4 BOTTOM	M27A TOP	M27A BOTTOM	M27B TOP	M27B BOTTOM
MISSING DATA:										
Alkalinity	xxxxx	xxxxx	xxxxx	xxxxx		xxxxx	xxxxx	xxxxx	xxxxx	xxxxx
Chloride	xxxxx									
Redox Potential										
Temperature										
BALANCES:										
% Error	-2.00%	3.00%	-1.00%	1.00%	-3.00%	1.00%	-1.00%	-1.00%	-4.00%	-32.00%
PHR Electrical	-0.033%	0.032%	-0.003%	0.004%	-0.155%	-0.029%	-0.131%	-0.116%	-0.184%	-2.090%
MINERALS:										
Al(OH)SO4						0.110				
Al4SO4(OH)10						0.944				
Alunite						4.808				
Boehmite						-0.789				
Diaspore						1.062				
Gibbsite						-0.765				
Chalcedonite			-0.550	-0.510			-0.990			
Cristobalite			-0.438	-0.396			-0.884	-0.922		
Quartz	-0.910		0.016	0.060			-0.435	-0.473	-0.852	-0.992
Fe(OH)3	-0.297	2.580	0.561	0.781	0.859	0.256	1.857	3.073	0.171	
Fe(OH)2.7			3.281	3.292	4.168	3.499	4.686	5.650	2.984	1.570
Goethite	1.505	4.382	2.049	2.228	2.466	1.844	3.445	4.661	1.619	0.125
Hematite	7.962	13.716	9.010	9.362	9.860	8.612	11.814	14.246	8.144	5.162
Jarosite										
Lepidocrocite	1.003	3.880	1.861	2.081	2.159	1.556	3.157	4.373	1.471	-0.063
Maghemite		4.110	0.072	0.511	0.667	-0.538	2.664	5.096	-0.707	
Magnetite	6.243	12.201	6.702	6.246	6.970	6.102	11.667	15.474	5.345	1.660
Mg-ferrite		1.141						2.596		
Gypsum	-0.753	-0.821			-0.494	-0.501	-0.127	-0.131	-0.122	0.002
Celestite							-0.8944	-0.9014	-0.8906	-0.6684
Cu metal										
Cuprite										
Cuprous-ferrite										
Cupric-ferrite										
ZnSiO3										
Anglesite										
Na-nontronite						2.485				
K-nontronite						3.021				
Ca-nontronite						9.259				
Mg-nontronite						8.876				
Chlorite-Fe						10.026				
Montmorillonite										

Blanks represent values < -1.000

LOG[IAP/KT] values from "PHREEQE" for OCTOBER 1990 ANALYSES:

SAMPLE #	21	22	23	24	25	26	27	28	29	30
SOURCE	M55	M56	WILD RICE	MILL POND	DAVE'S DAM	CHARA POND	POLISH POND	BOOMER. LANDING	BOOMER. OUTFLOW	MUD LAKE OUTFLOW
MISSING DATA:										
Alkalinity			xxxxx			xxxxx	xxxxx	xxxxx	xxxxx	
Chloride			xxxxx			xxxxx				
Redox Potential			xxxxx		xxxxx			xxxxx	xxxxx	
Temperature			xxxxx		xxxxx			xxxxx		
BALANCES:										
% Error	16.00%	-15.00%	39.00%	-5.00%	-5.00%	6.00%	0.00%	-11.00%	-19.00%	5.00%
PHR Electrical	-0.487%	-0.686%	0.016%	-0.329%	-0.048%	0.075%	0.002%	-0.077%	-0.014%	-0.797%
MINERALS:										
Al(OH)SO4				-0.309	-0.749					
Al4SO4(OH)10								5.359		
Alunite										
Boehmite								1.529		
Diaspore								3.328		
Gibbsite								1.475		
Chalcedonite	-0.461	-0.610		-0.238	-0.460			-0.636		
Cristobalite	-0.375	-0.515		-0.124	-0.360			-0.543		
Quartz	0.058	-0.074		0.332	0.084			-0.105		
Fe(OH)3	1.327	1.216	-0.386	1.589		2.661	2.522	1.965	1.645	-0.360
Fe(OH)2.7	4.222	4.317		4.902			5.270	4.454	4.297	2.537
Goethite	3.242	2.980	1.416	3.036		4.463	3.970	3.766	3.634	1.365
Hematite	11.451	10.907	7.783	10.979		13.877	12.846	12.485	12.243	7.672
Jarosite				2.879						
Lepidocrocite	2.627	2.517	0.914	2.889		3.961	3.822	3.265	2.945	0.940
Maghemite	1.605	1.383		2.128		4.272	3.995	2.880	2.239	
Magnetite	9.883	9.366	5.253	6.091		12.959	9.894	11.515	11.720	4.958
Mg-ferrite						1.559		-0.646		
Gypsum				-0.081		-0.755				
Celestite										
Cu metal										
Cuprite										
Cuprous-ferrite				5.005	2.870					
Cupric-ferrite				4.042						
ZnSiO3								0.324		
Anglesite										
Na-nontronite				10.247				12.331		
K-nontronite										
Ca-nontronite				17.548	2.835			19.545		
Mg-nontronite				17.175	2.441			19.161		
Chlorite-Fe				-0.714				26.315		
Montmorillonite								1.240		

Blanks represent values (-1.000

TABLE 8. OXIDATION/PRECIPITATION RATES

RATE CALCULATIONS

Based on 0.15 m inert cover on tailings

LOCATION and setting		UNSATURATED TAILINGS, m MAX.	UNSATURATED TAILINGS, m MIN.	[S], mg/L MAX.	[S], mg/L MIN.	[S], millimole/L MAX.	[S], millimole/L MIN.
4	B	3.05	2.90	1249	1233	38.96	38.46
5A	B	1.53	1.53	1254	327	39.11	10.20
5B	B	1.53	1.50	1616	591	50.41	18.43
7A	T	2.96	1.81	6735	3009	210.07	93.86
7B	B	3.27	2.09	5193	2459	161.98	76.70
9	B	3.65	2.68	2197	1589	68.53	49.56
24A	B	1.98	1.98	2761	864	86.12	26.95
24B	B	1.98	1.98	1749	1251	54.55	39.02
25	B	0.97	0.00	32	32	1.00	1.00
26	B	0.92	0.35	99	29	3.09	0.90
27A	T	2.55	1.15	211	44	6.58	1.37
27B	T	2.41	0.87	542	181	16.91	5.65
30	B	1.22	0.17	56	12	1.75	0.37
32	B	2.59	2.50	1401	1035	43.70	32.28
40	B	2.75	1.61	1321	802	41.20	25.02
41	B	1.46	0.16	137	20	4.27	0.62
43	B	2.98	1.47	2600	2030	81.10	63.32
46	B	3.78	2.77	2028	1434	63.26	44.73
H1	T	1.81	0.37	621	607	19.37	18.93
H2	T	2.70	1.09	1453	1336	45.32	41.67
H3	T	2.63	0.65	831	831	25.92	25.92
H4	T	1.64	0.00	301	176	9.39	5.49
H5	T	1.40	0.00	1497	417	46.69	13.01
H6	T	2.21	0.74	1864	1840	58.14	57.39
H7	T	2.33	0.93	1269	1269	39.58	39.58
H8	T	1.86	0.34	10198	3878	318.09	120.96
Averages		2.24	1.22	1893	1050	59.0	32.7
Overall AVE.			1.73		1471		45.9
		Unsaturated, m		[S], mg/L		[S], millimole/L	

H1-H3 go DRY; M27, H1-H8 have TD in tailings

TABLE 8. OXIDATION/PRECIPITATION RATES

SULFIDE OXIDATION RATES

AREA, m^2	200,000
RECHARGE, m 0.175 MIN., and	0.275 MAX.
MINERAL DENSITY, kg/m^3	3650
POROSITY, fraction	0.3
BULK DENSITY, kg/m^3	2555

LOCATION and setting		[S], millimole/L (corrected, App.I-1) MAX.	[S], millimole/L (corrected, App.I-1) MIN.	S FLUX mole.m-2.yr-1 [S MAX]* (P MIN)	S FLUX mole.m-2.yr-1 [S MIN]* (P MAX)	mole.m-2.m-1.yr-1 [S MAX]* (P MIN)/ UNSAT.MAX	mole.m-2.m-1.yr-1 [S MIN]* (P MAX)/ UNSAT.MIN	SULFIDE OXIDATION mole.kg-1.yr-1 "MAX."	SULFIDE OXIDATION mole.kg-1.yr-1 "MIN."
4	B	38.96	38.46	6.8	10.6	2.24	3.65	0.0009	0.0014
5A	B	39.11	10.20	6.8	2.8	4.47	1.83	0.0018	0.0007
5B	B	50.41	18.43	8.8	5.1	5.77	3.38	0.0023	0.0013
7A	T	210.07	183.27	36.8	50.4	12.41	27.81	0.0049	0.0109
7B	B	161.98	76.70	28.3	21.1	8.67	10.09	0.0034	0.0040
9	B	68.53	49.56	12.0	13.6	3.29	5.09	0.0013	0.0020
24A	B	86.12	90.92	15.1	25.0	7.61	12.63	0.0030	0.0049
24B	B	54.55	39.02	9.5	10.7	4.82	5.42	0.0019	0.0021
25	B	1.00	1.00	0.2	0.3	0.18		0.0001	
26	B	3.09	0.90	0.5	0.2	0.59	0.71	0.0002	0.0003
27A	T	6.58	1.37	1.2	0.4	0.45	0.33	0.0002	0.0001
27B	T	16.91	5.65	3.0	1.6	1.23	1.79	0.0005	0.0007
30	B	1.75	0.37	0.3	0.1	0.25		0.0001	
32	B	43.70	32.28	7.6	8.9	2.95	3.55	0.0012	0.0014
40	B	41.20	25.02	7.2	6.9	2.62	4.27	0.0010	0.0017
41	B	4.27	0.62	0.7	0.2	0.51		0.0002	
43	B	81.10	89.16	14.2	24.5	4.76	16.66	0.0019	0.0065
46	B	63.26	44.73	11.1	12.3	2.93	4.44	0.0011	0.0017
H1	T	19.37	18.93	3.4	5.2	1.87	14.08	0.0007	0.0055
H2	T	45.32	41.67	7.9	11.5	2.94	10.52	0.0011	0.0041
H3	T	25.92	25.92	4.5	7.1	1.72	10.96	0.0007	0.0043
H4	T	9.39	5.49	1.6	1.5	1.00		0.0004	
H5	T	46.69	13.01	8.2	3.6	5.84		0.0023	
H6	T	58.14	57.39	10.2	15.8	4.60	21.32	0.0018	0.0083
H7	T	39.58	39.58	6.9	10.9	2.97	11.70	0.0012	0.0046
H8	T	318.09	136.68	55.7	37.6	29.86	109.10	0.0117	0.0427
Averages		59.0	40.2	10.3	11.1	4.5	13.3	0.0018	0.0052
Overall AVE			49.6		10.7		8.4		0.0033

	[S]corr., millimole/L	S FLUX mole.m-2.yr-1	S production Rate mole.m-2.m-1.yr-1	SULFIDE OXIDATION mole.kg-1.yr-1
		209,843 kg H2SO4/yr		

TABLE 8. OXIDATION/PRECIPITATION RATES

IRON PRECIPITATION RATES

AREA, m^2	200,000	200,000
RECHARGE, m	0.175 MIN., and	0.275 MAX.
MINERAL DENSITY, kg/m^3		3650
POROSITY, fraction		0.3
BULK DENSITY, kg/m^3		2555

LOCATION and setting		Fe LOSS (based on PYRITE) millimole/L		Fe LOSS mole.m-2.yr-1		mole.m-2.m-1.yr-1		IRON PRECIPITATION mole.kg-1.yr-1	
		MAX.	MIN.	[Fe MAX]* (P MIN)	[Fe MIN]* (P MAX)	[Fe MAX]* (P MIN)/ UNSAT.MAX	[Fe MIN]* (P MAX)/ UNSAT.MIN	"MAX."	"MIN."
4	B	7.26	0.24	1.27	0.07	0.4166	0.0228	0.000163	0.000009
5A	B	7.93	2.98	1.39	0.82	0.9070	0.5356	0.000355	0.000210
5B	B	5.69	4.13	1.00	1.14	0.6508	0.7569	0.000255	0.000296
7A	T								
7B	B								
9	B								
24A	B								
24B	B								
25	B	0.47	0.47	0.08	0.13	0.0847		0.000033	
26	B	1.00	0.25	0.18	0.07	0.1904	0.1971	0.000075	0.000077
27A	T	3.05	0.67	0.53	0.18	0.2093	0.1601	0.000082	0.000063
27B	T	8.34	2.47	1.46	0.68	0.6058	0.7814	0.000237	0.000306
30	B	0.46	0.17	0.08	0.05	0.0660		0.000026	
32	B								
40	B	10.08	9.69	1.76	2.66	0.6413	1.6543	0.000251	0.000647
41	B	1.79	0.05	0.31	0.01	0.2146		0.000084	
43	B								
46	B								
H1	T	4.18	3.90	0.73	1.07	0.4042	2.8998	0.000158	0.001135
H2	T								
H3	T								
H4	T	4.47	1.86	0.78	0.51	0.4771		0.000187	
H5	T	18.85	5.44	3.30	1.50	2.3578		0.000923	
H6	T								
H7	T	0.71	0.71	0.12	0.20	0.0533	0.2099	0.000021	0.000082
H8	T	1.51	1.51	0.26	0.42	0.1417	1.2053	0.000055	0.000472
Averages		5.05	2.30	0.88	0.63	0.49	0.84	0.00019	0.00033
Overall AVE			3.68		0.76		0.63		0.00025

	Fe LOSS millimole/L	Fe LOSS mole.m-2.yr-1	Fe precipitation Rate mole.m-2.m-1.yr-1	IRON PRECIPITATION mole.kg-1.yr-1
		16,217 kg Fe(OH)3/yr		

Figure 1A

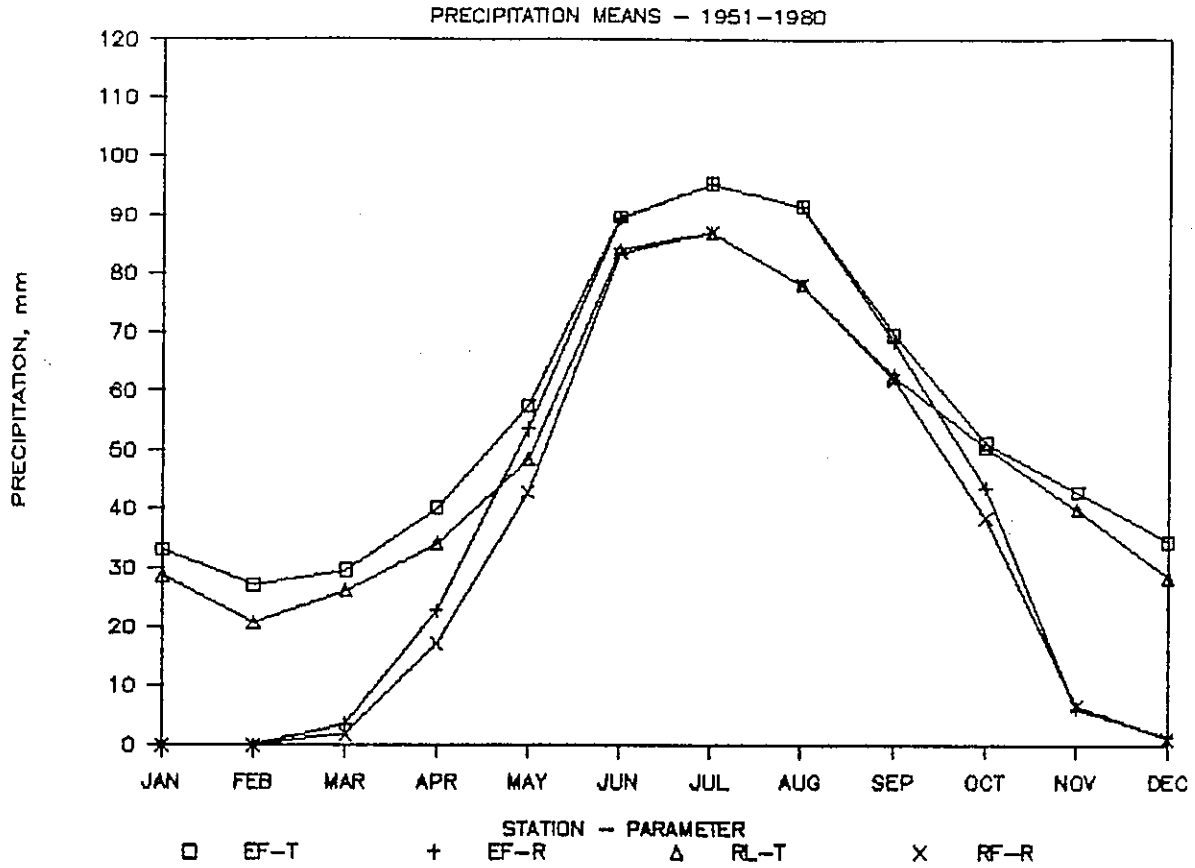


Figure 1B

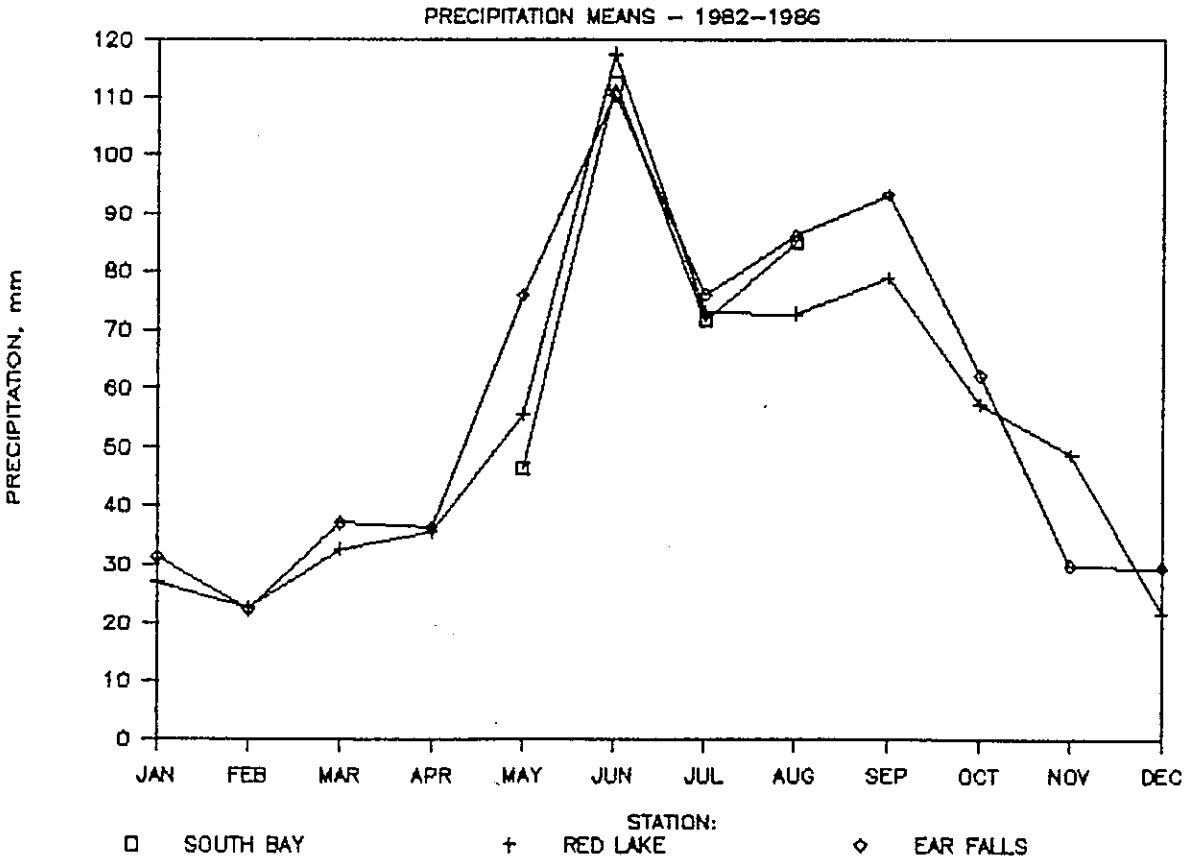


Figure 2A

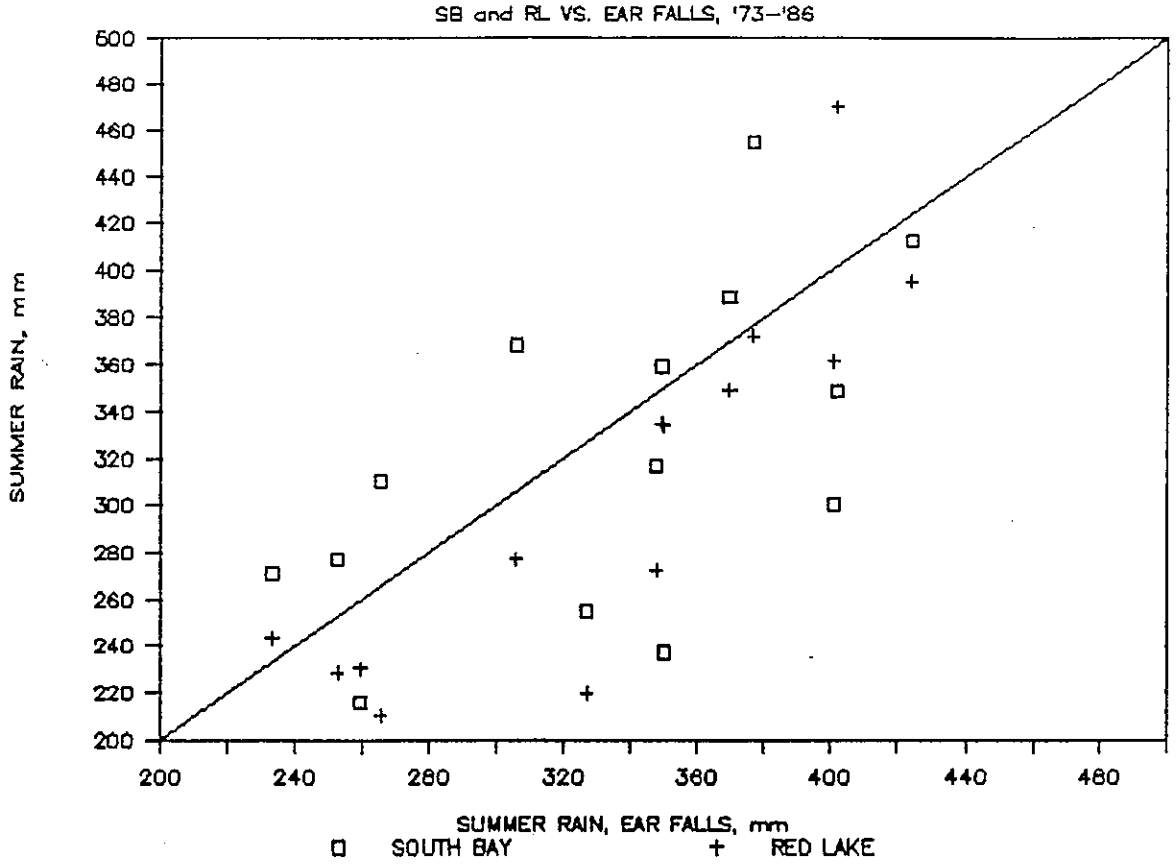


Figure 2B

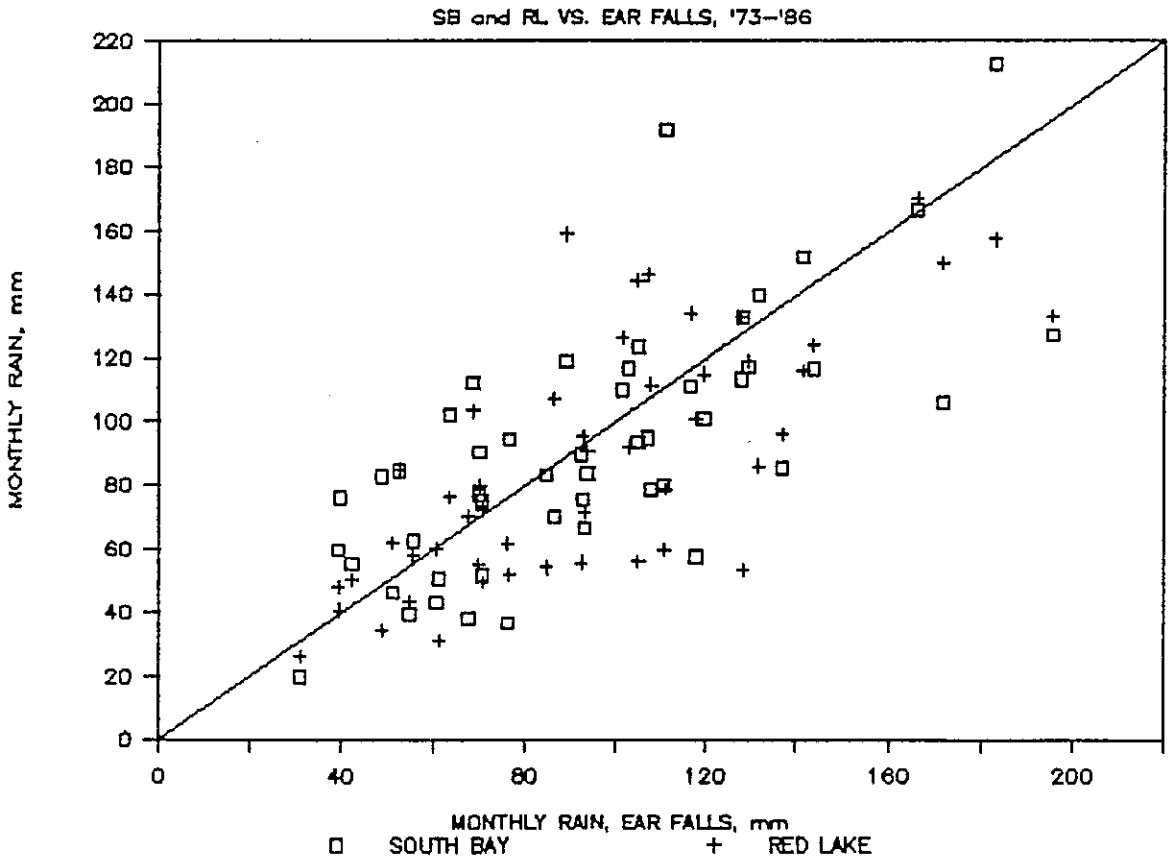


Figure 2C

SOUTH BAY VS. EAR FALLS, '73–'86

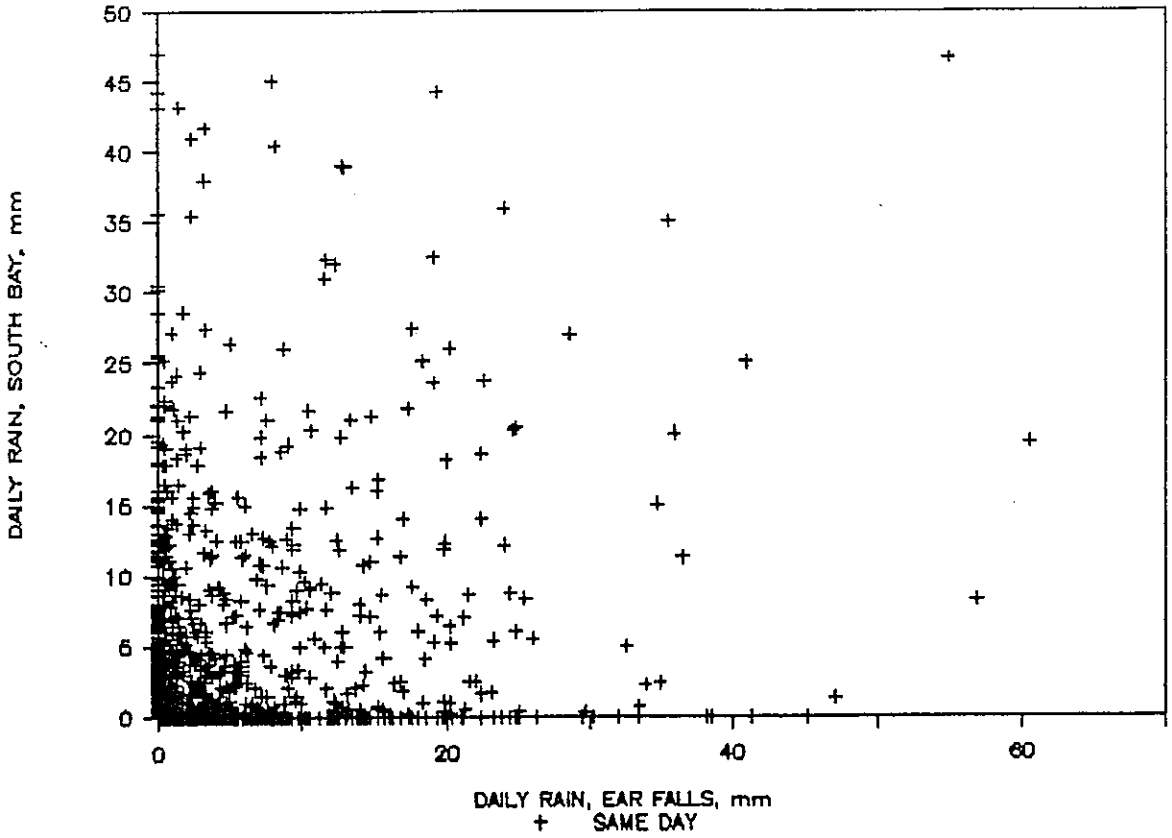


Figure 2D

SOUTH BAY VS. EAR FALLS, '73–'86

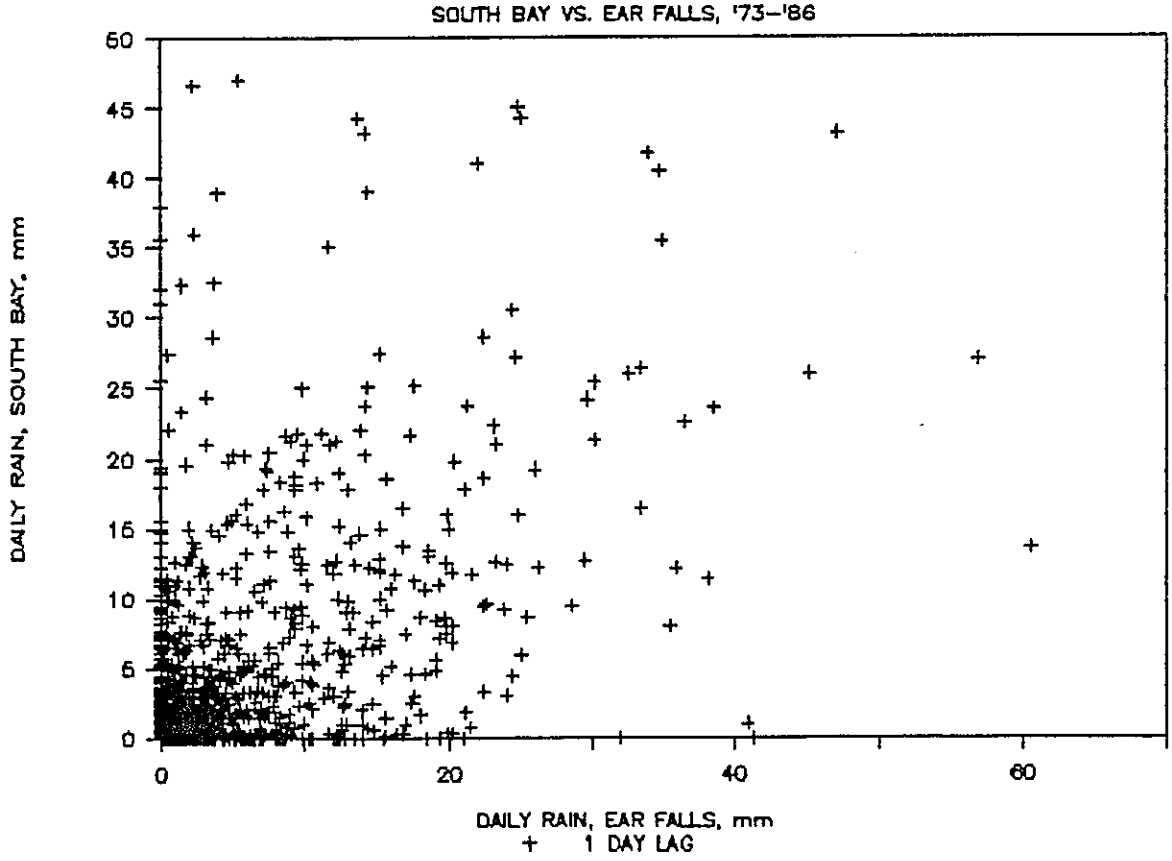


Figure 3A–1

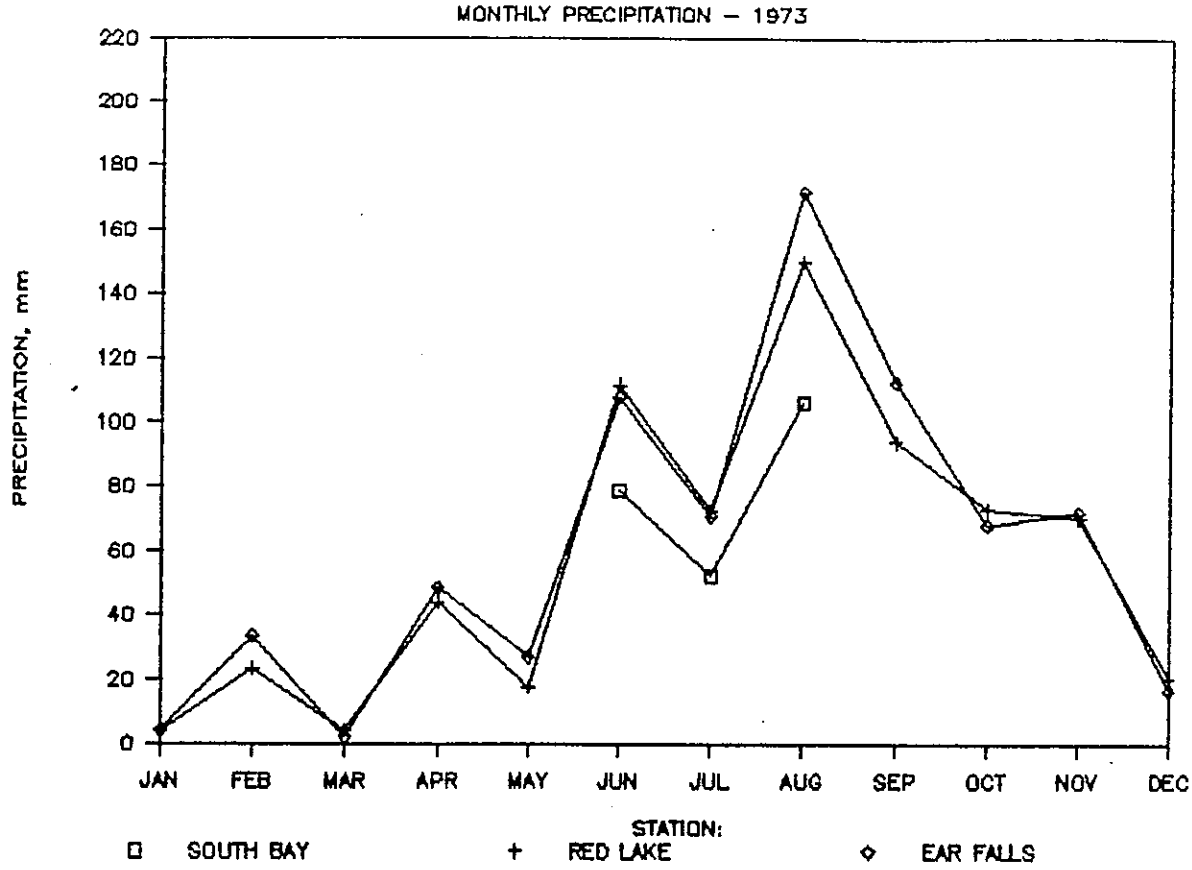


Figure 3A–2

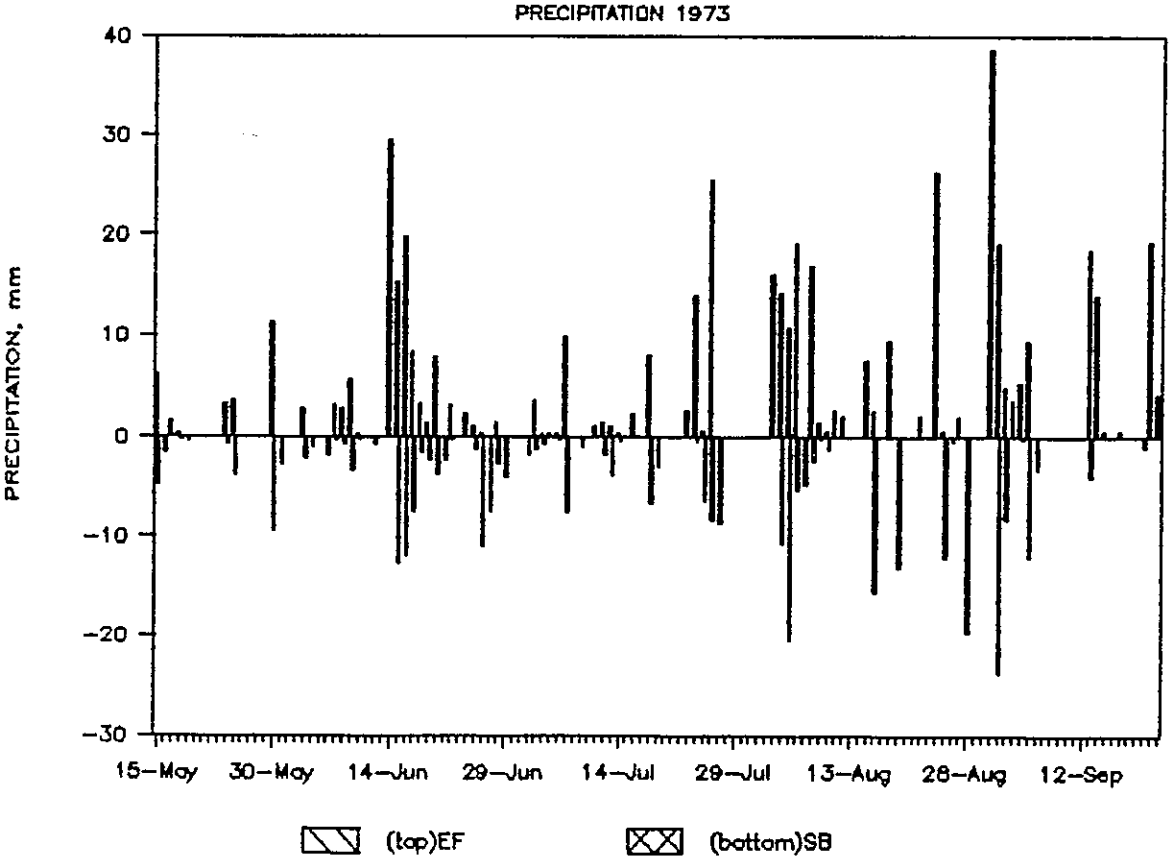


Figure 3B-1

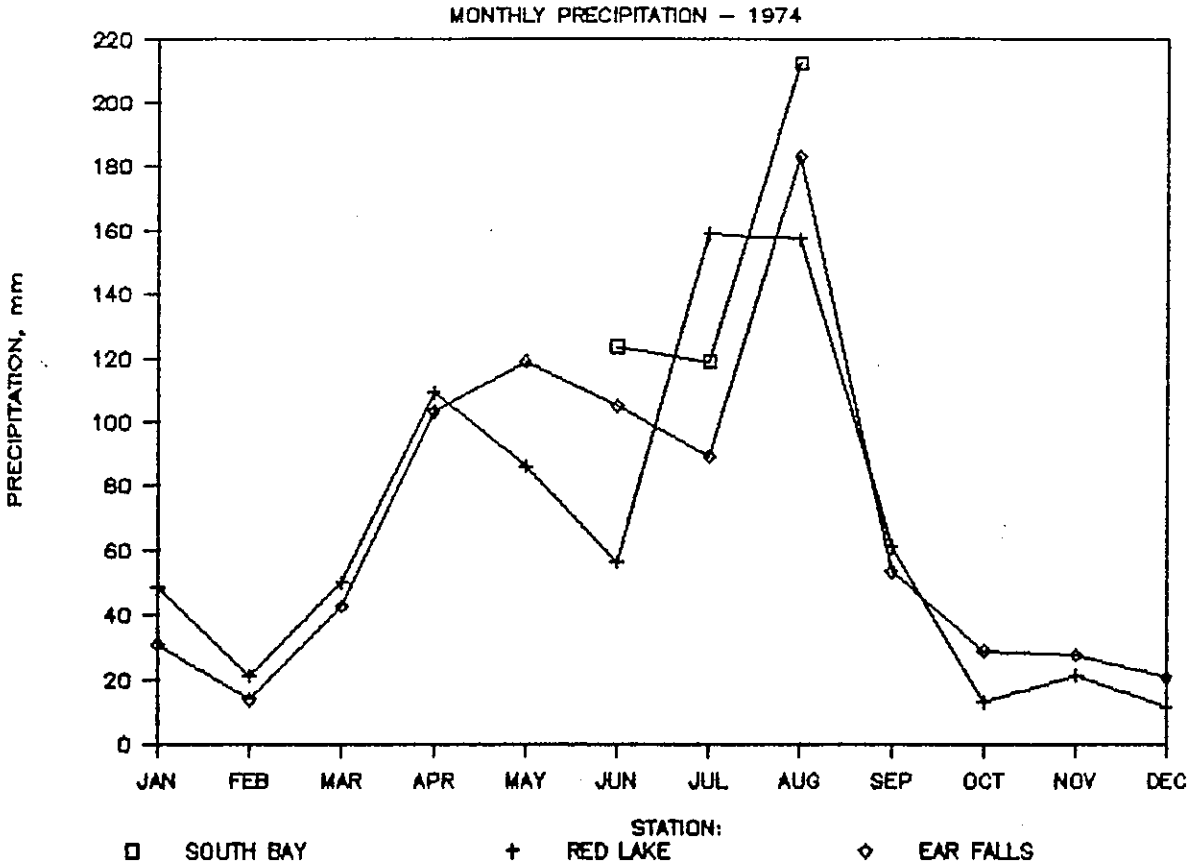


Figure 3B-2

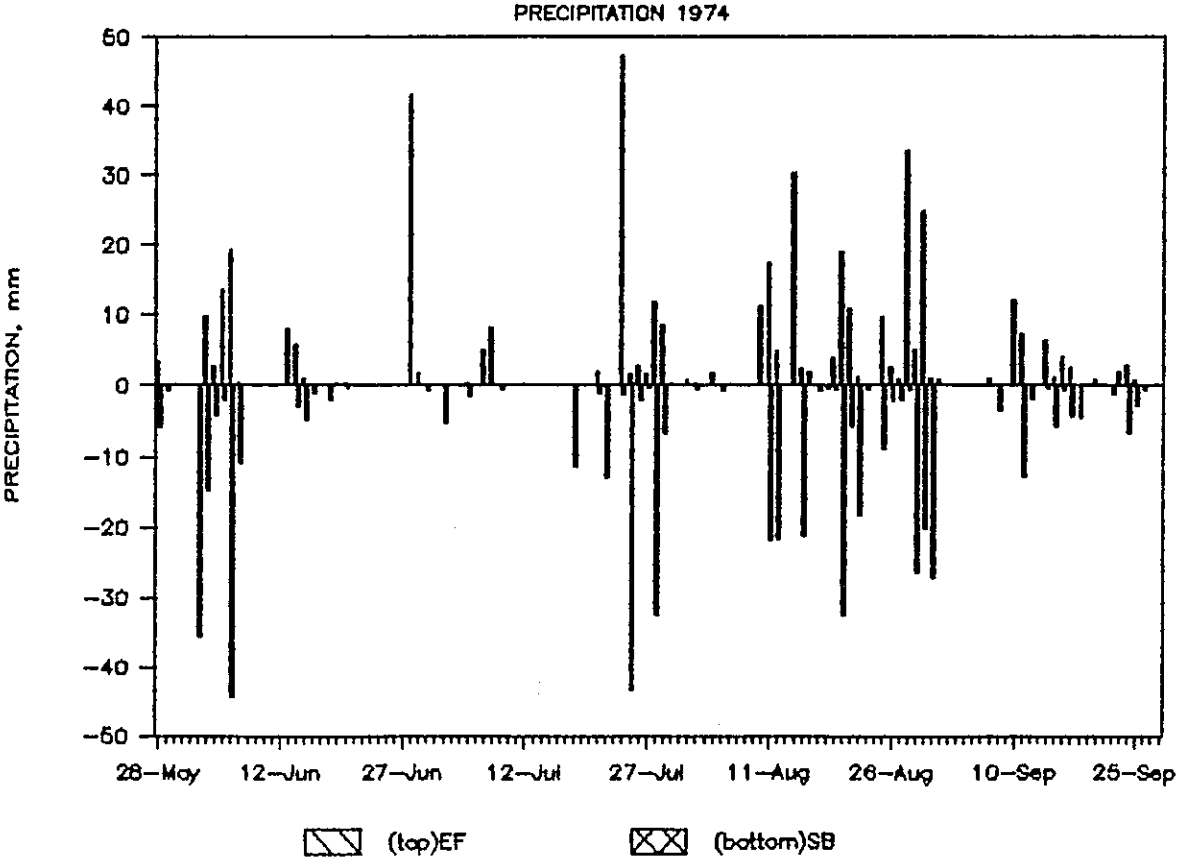


Figure 3C-1

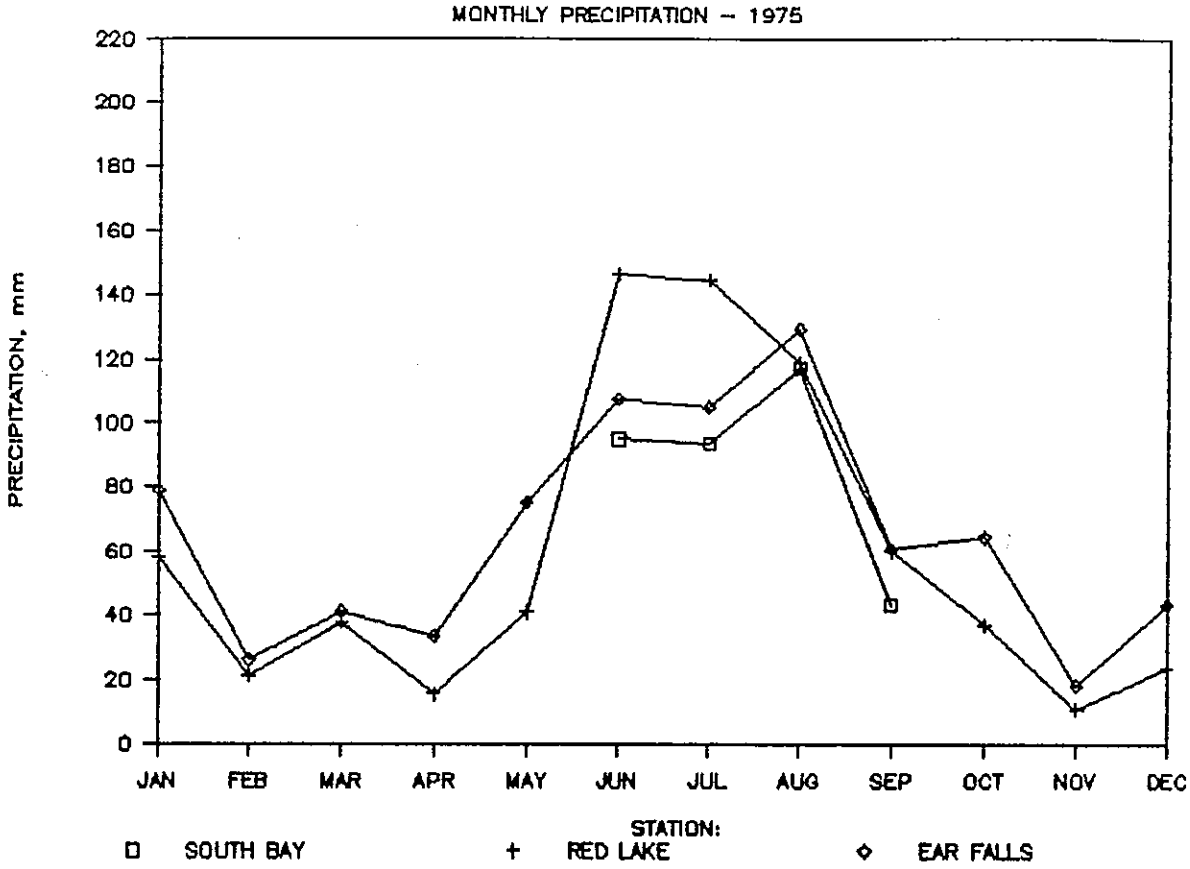


Figure 3C-2

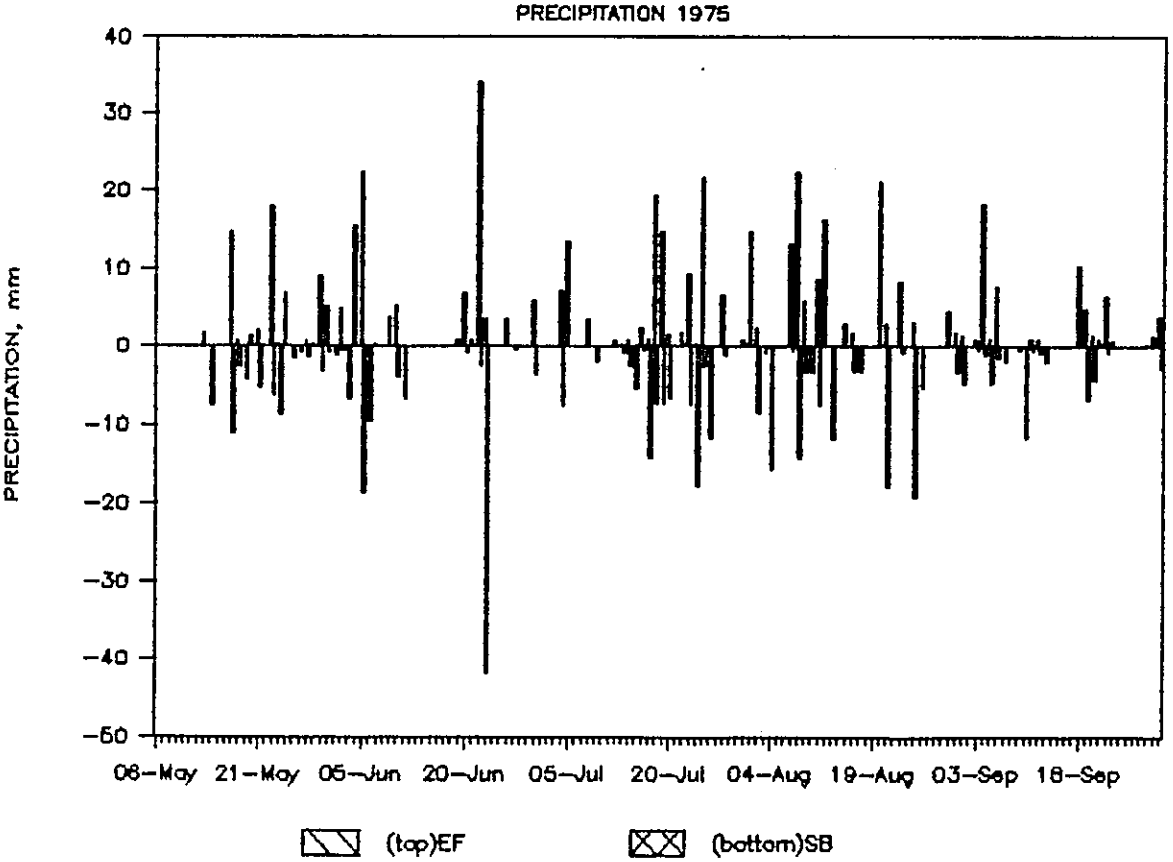


Figure 3D-1

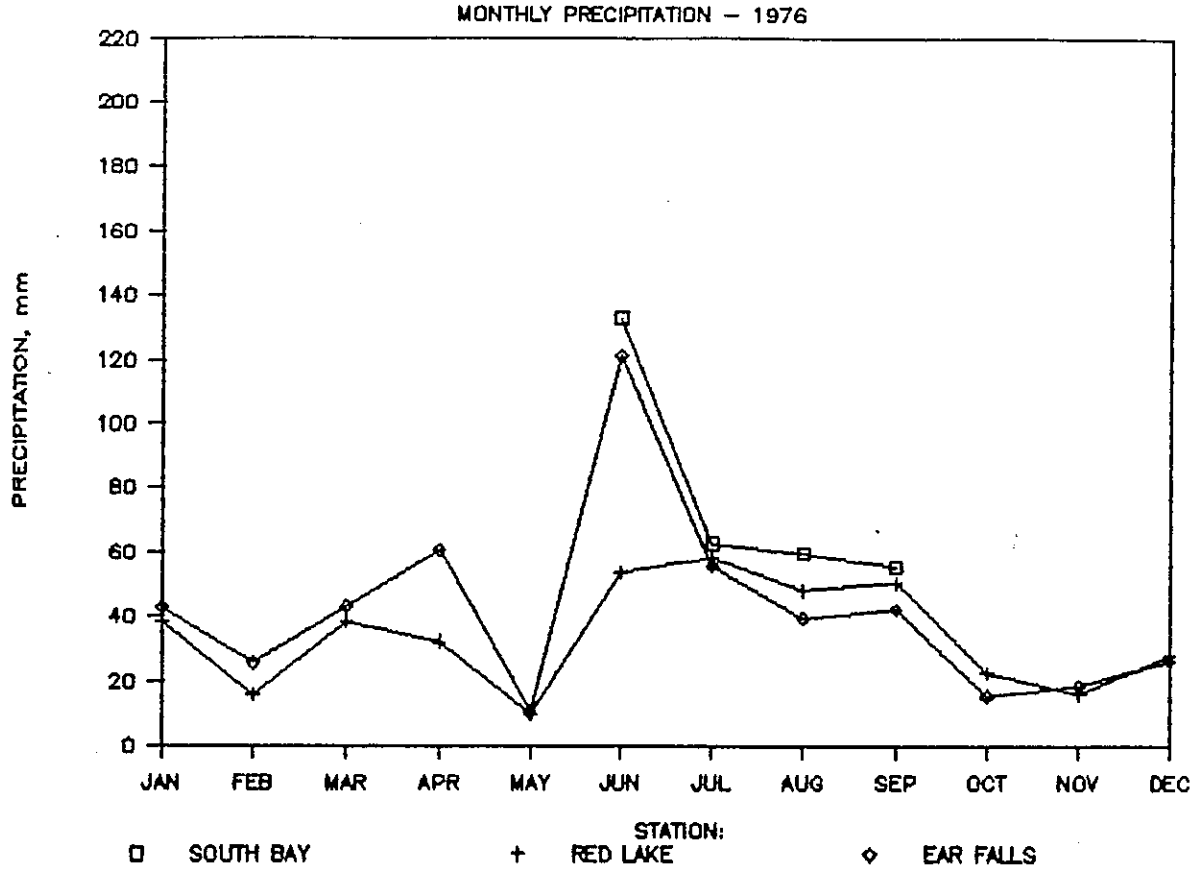


Figure 3D-2

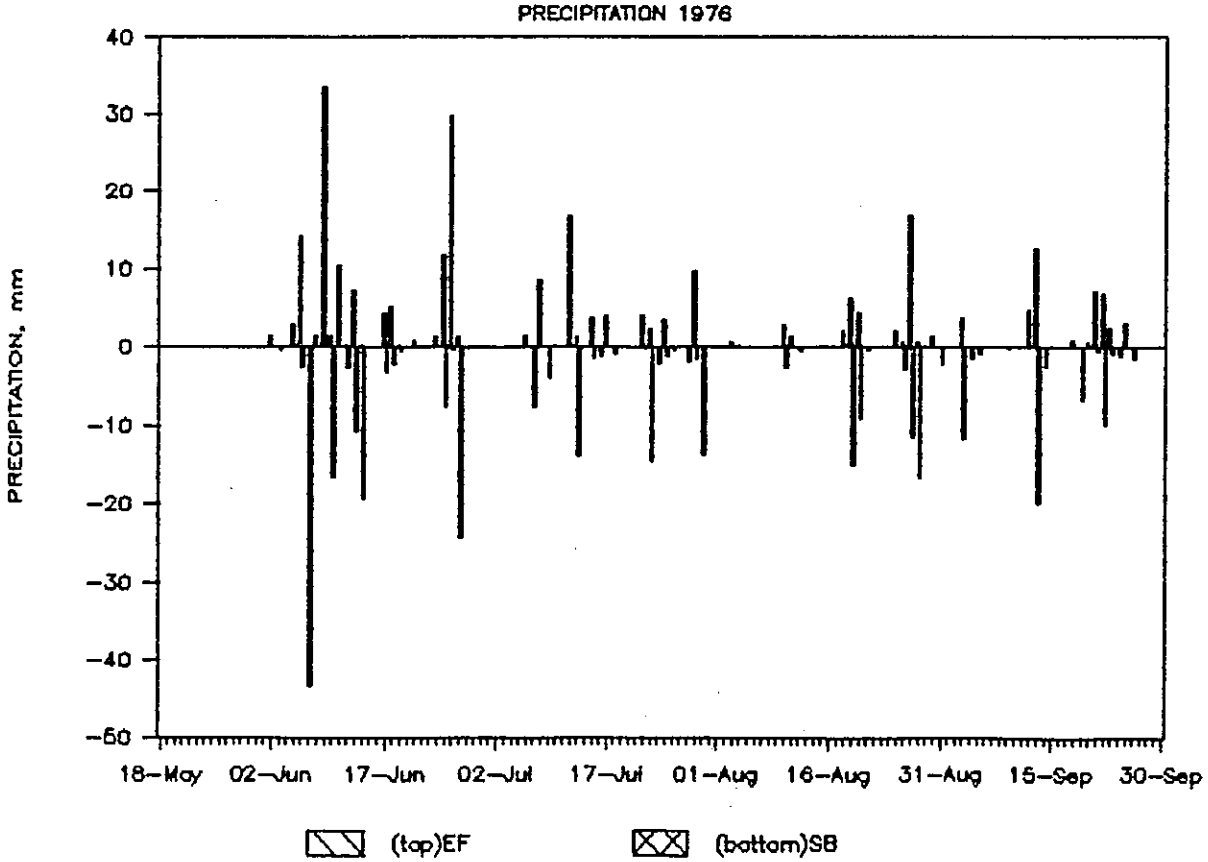


Figure 3E-1

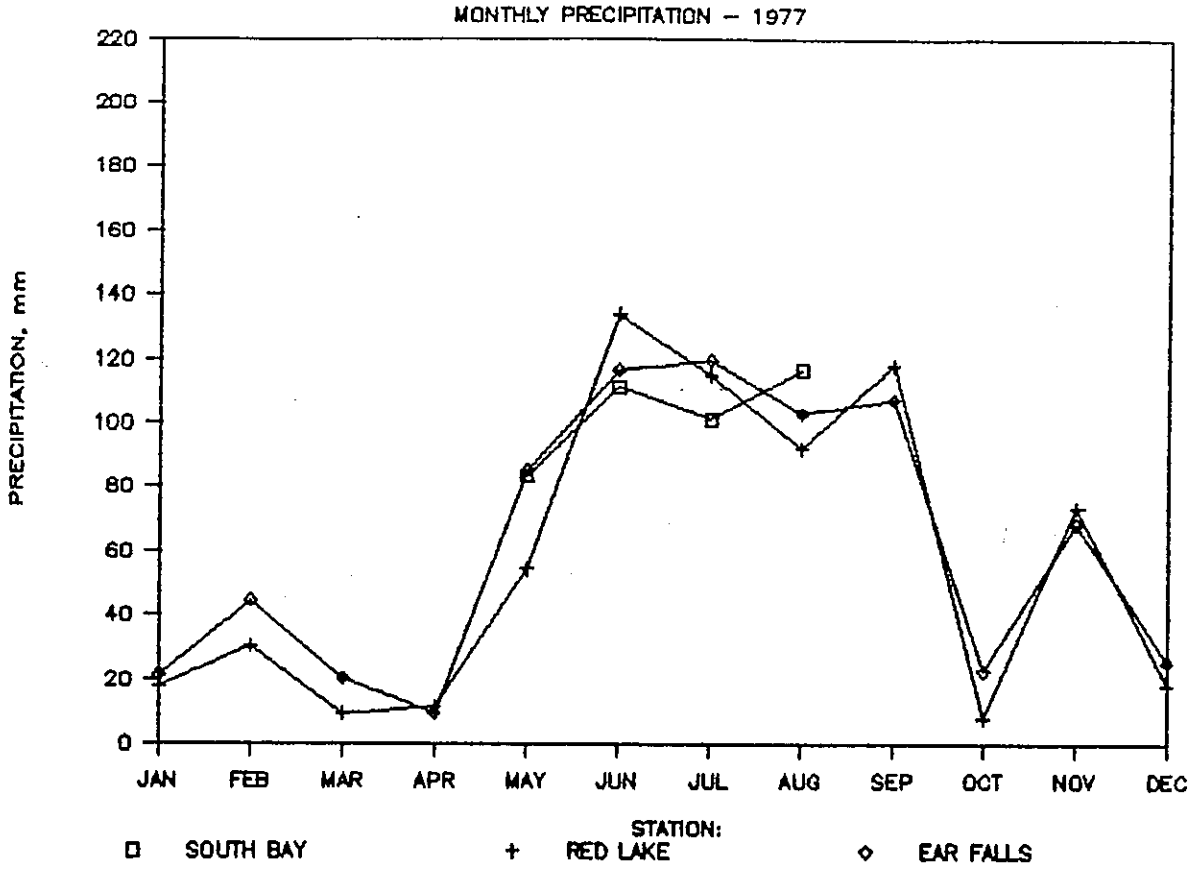


Figure 3E-2

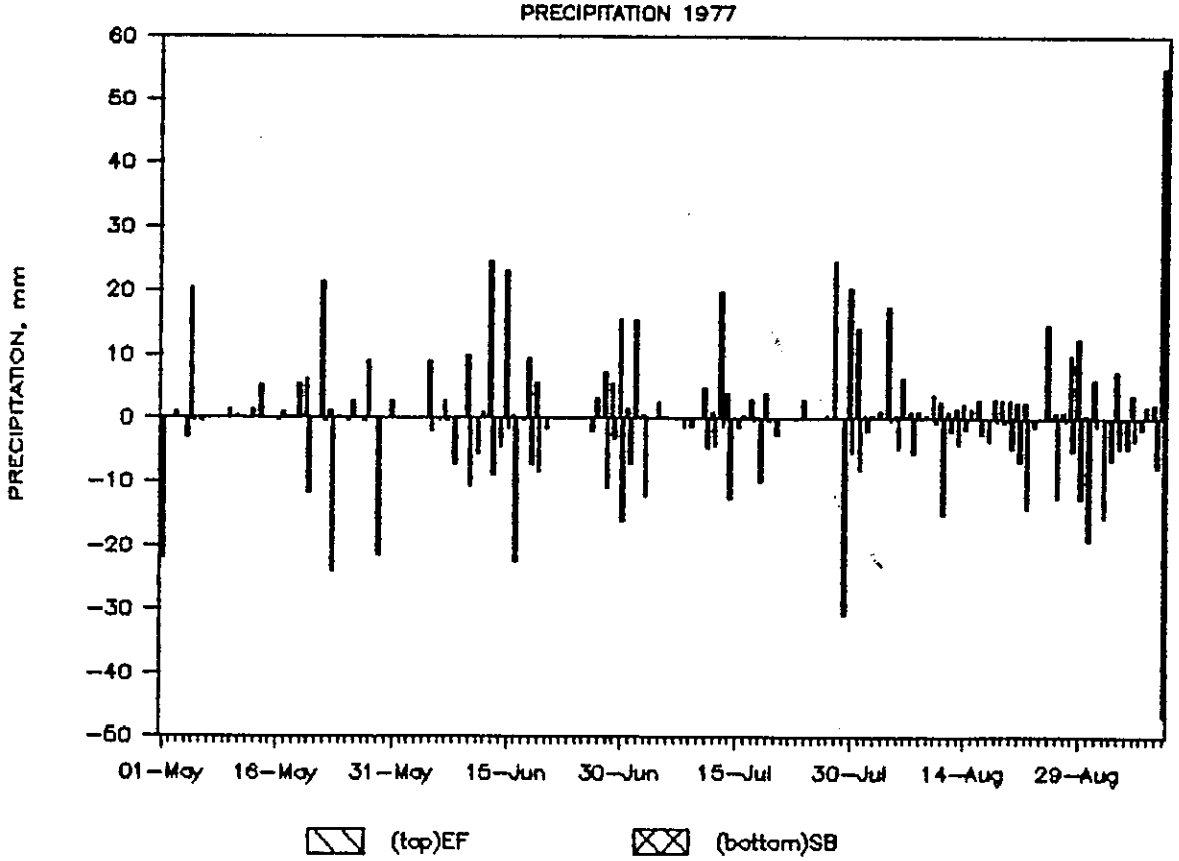


Figure 3F-1

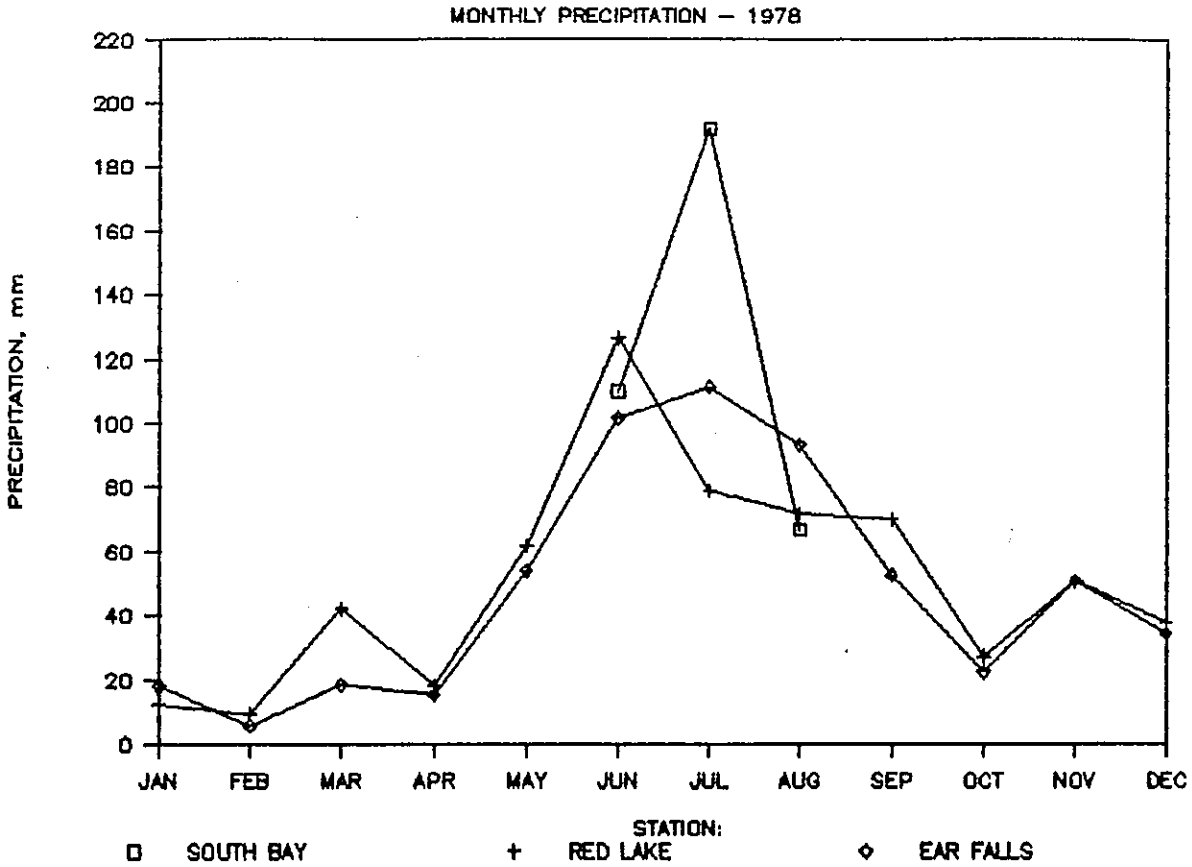


Figure 3F-2

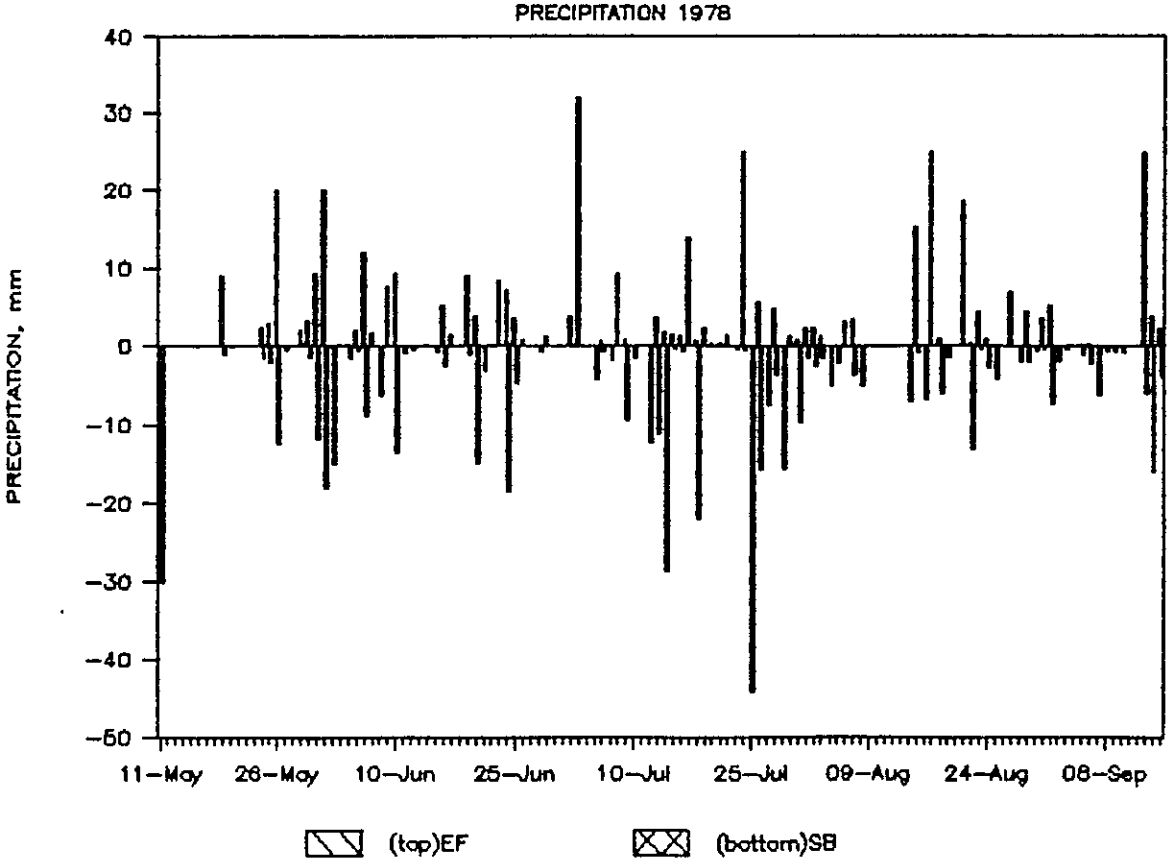


Figure 3G-1

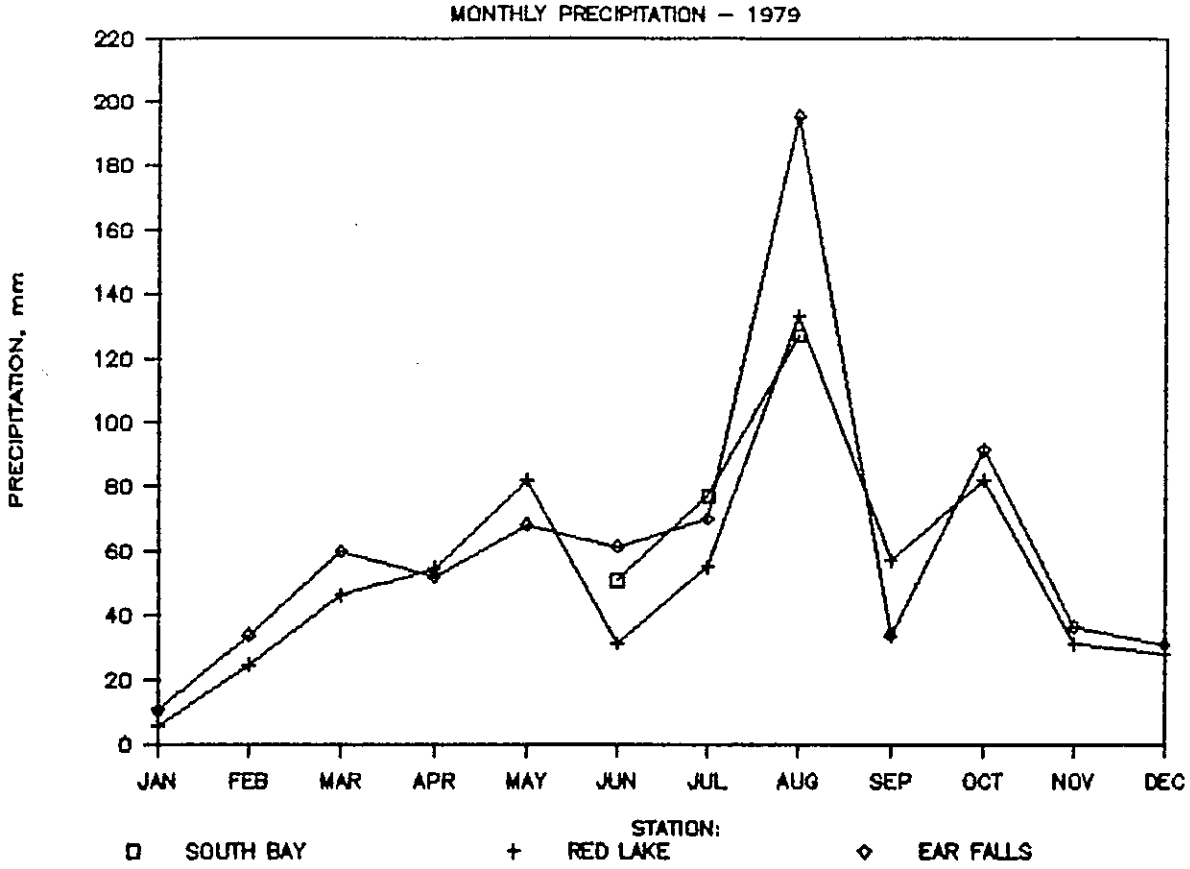


Figure 3G-2

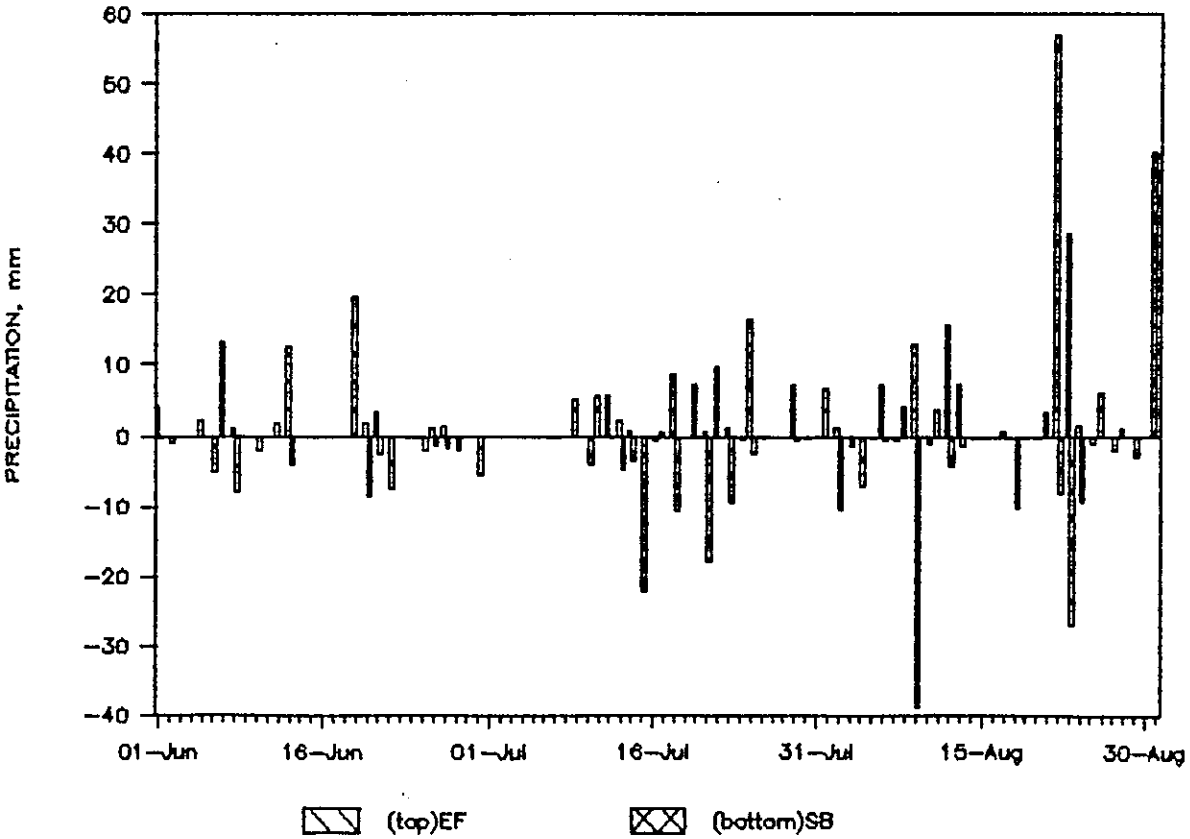


Figure 3H-1

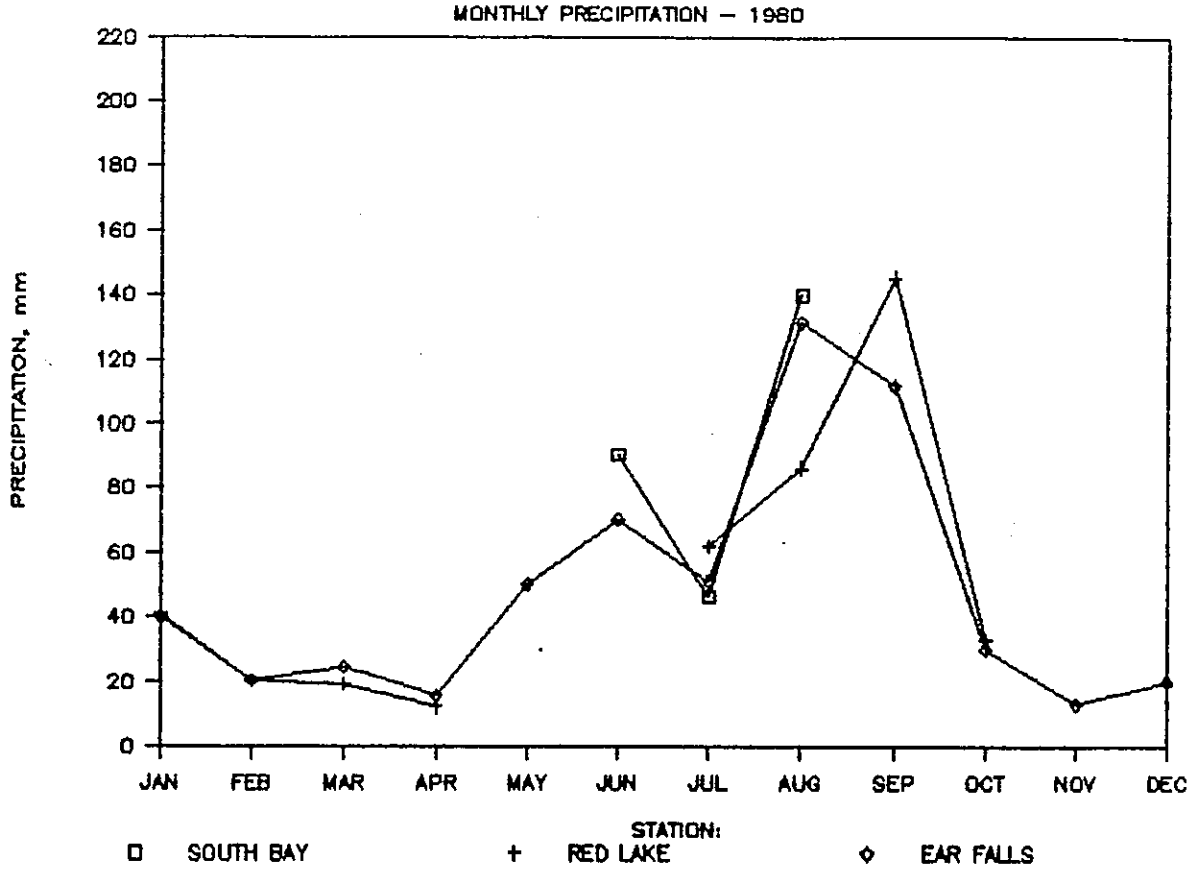


Figure 3H-2

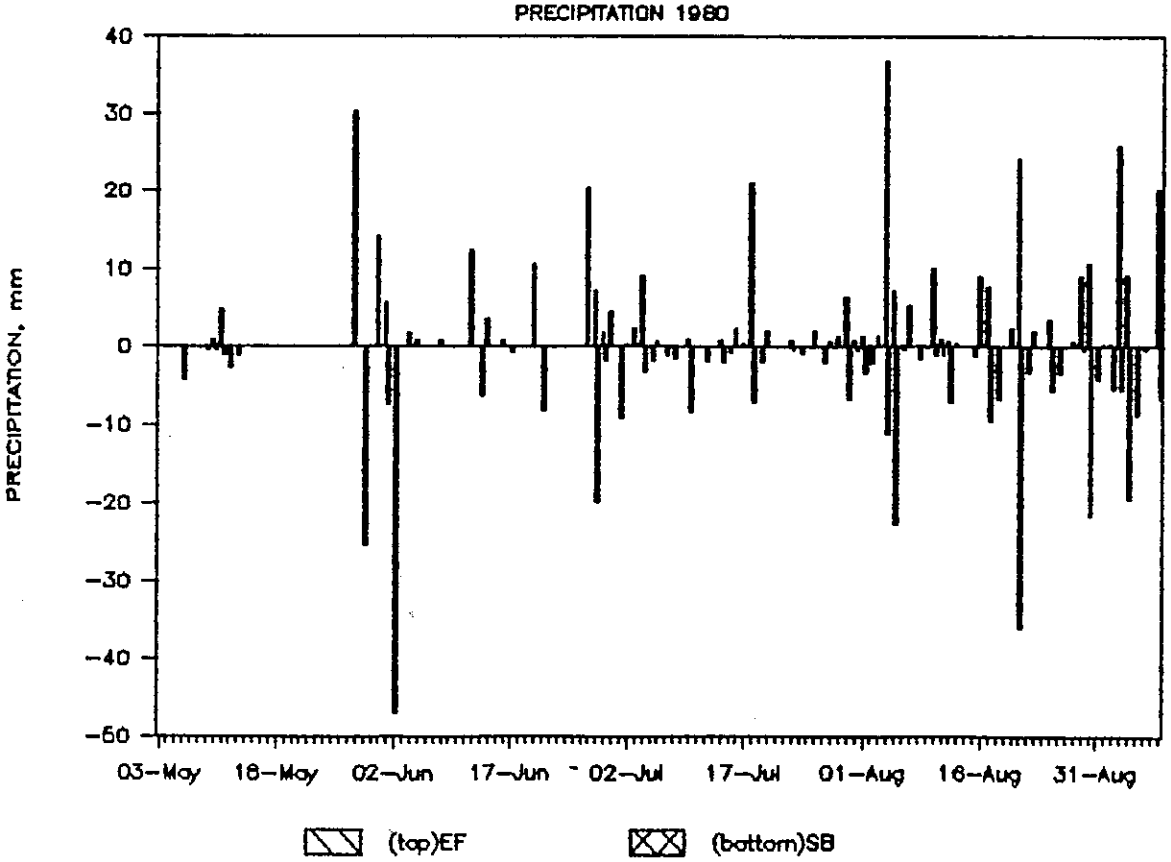


Figure 31-1

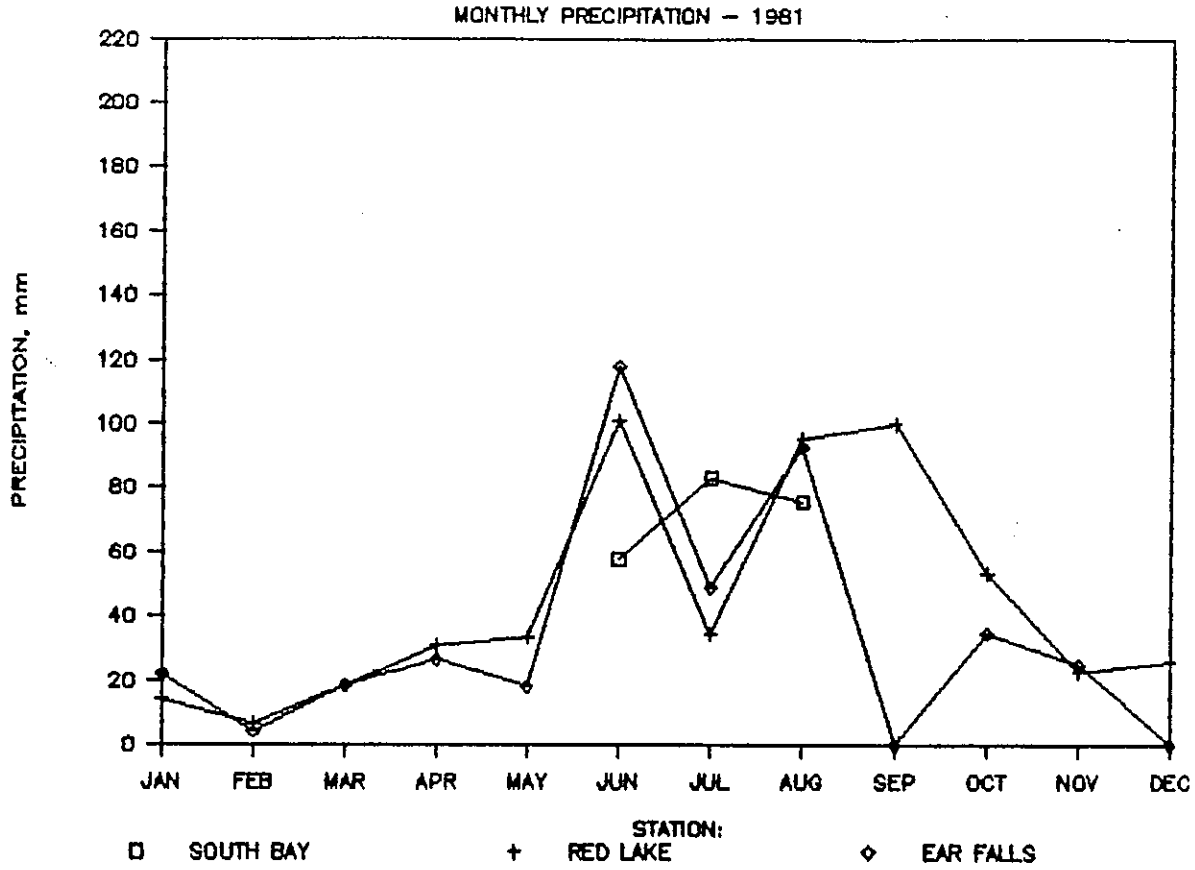


Figure 31-2

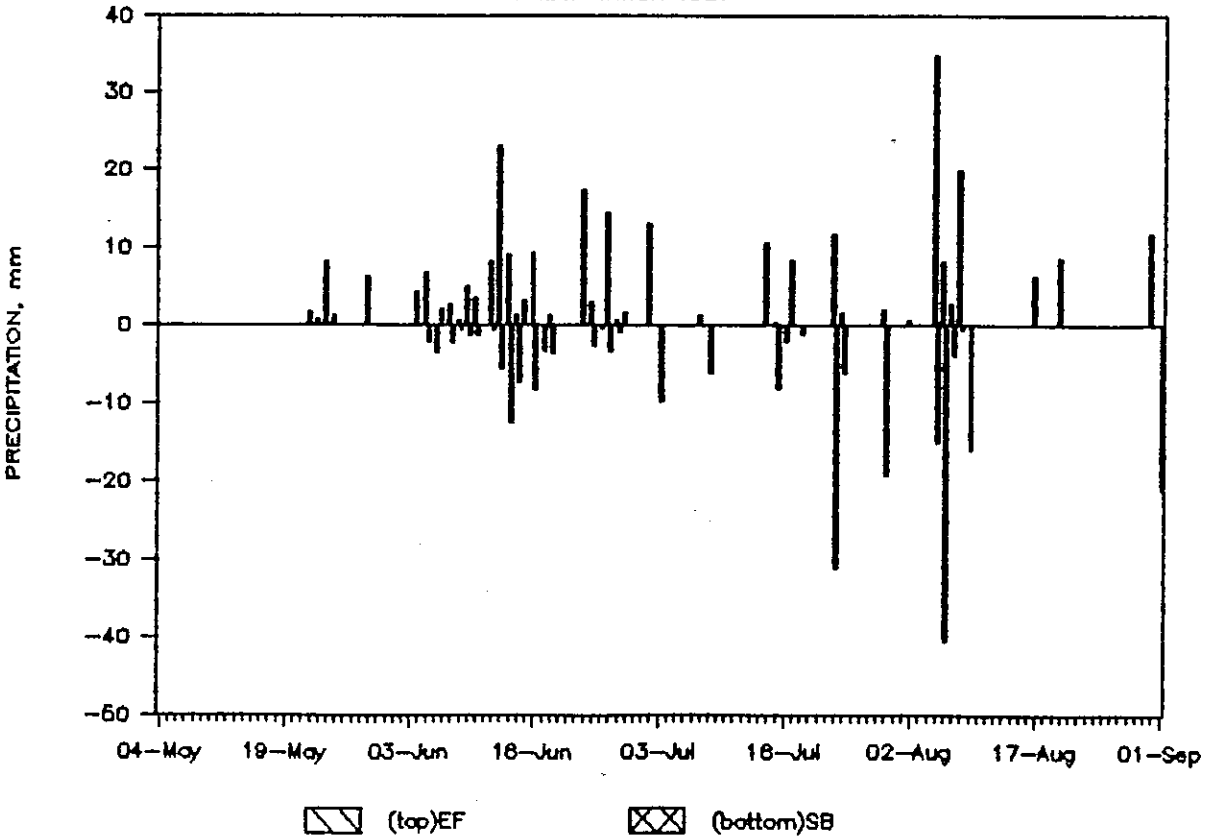


Figure 3J–1

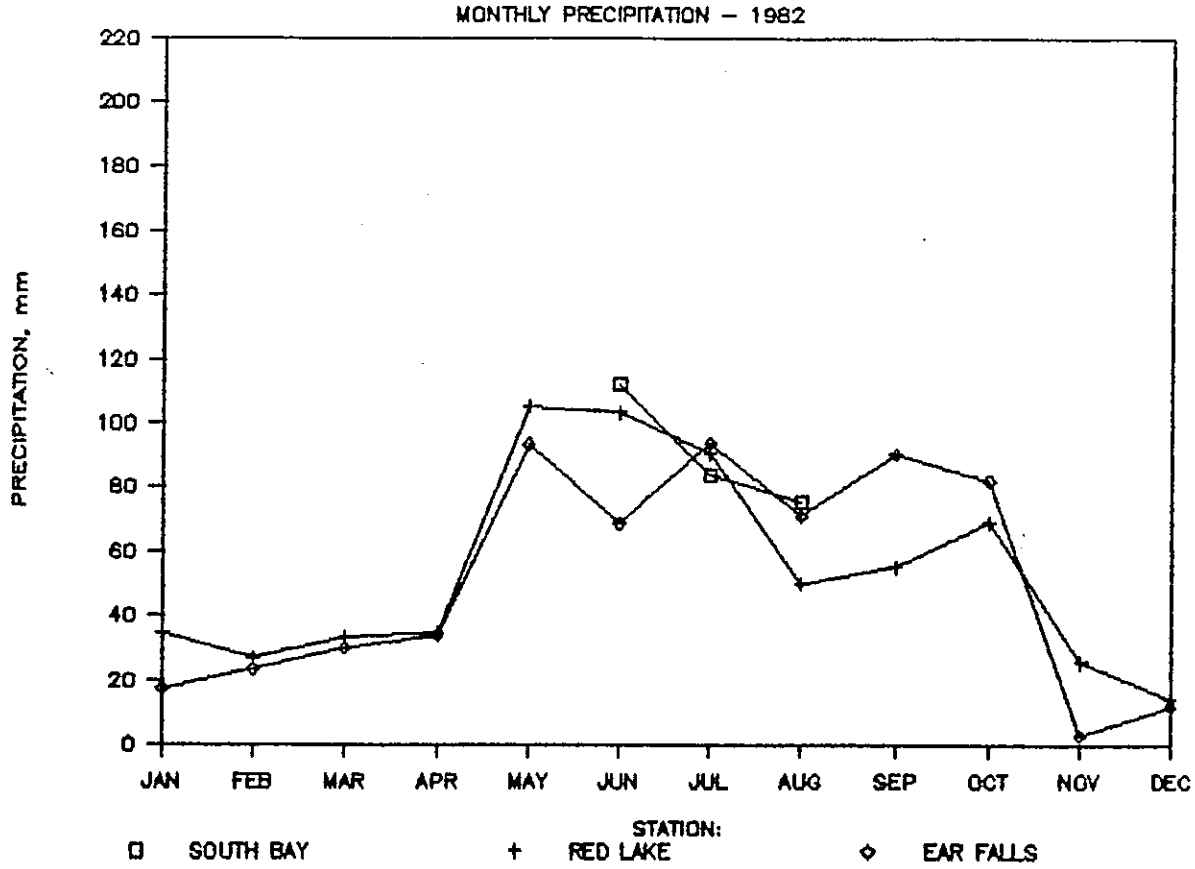


Figure 3J–2

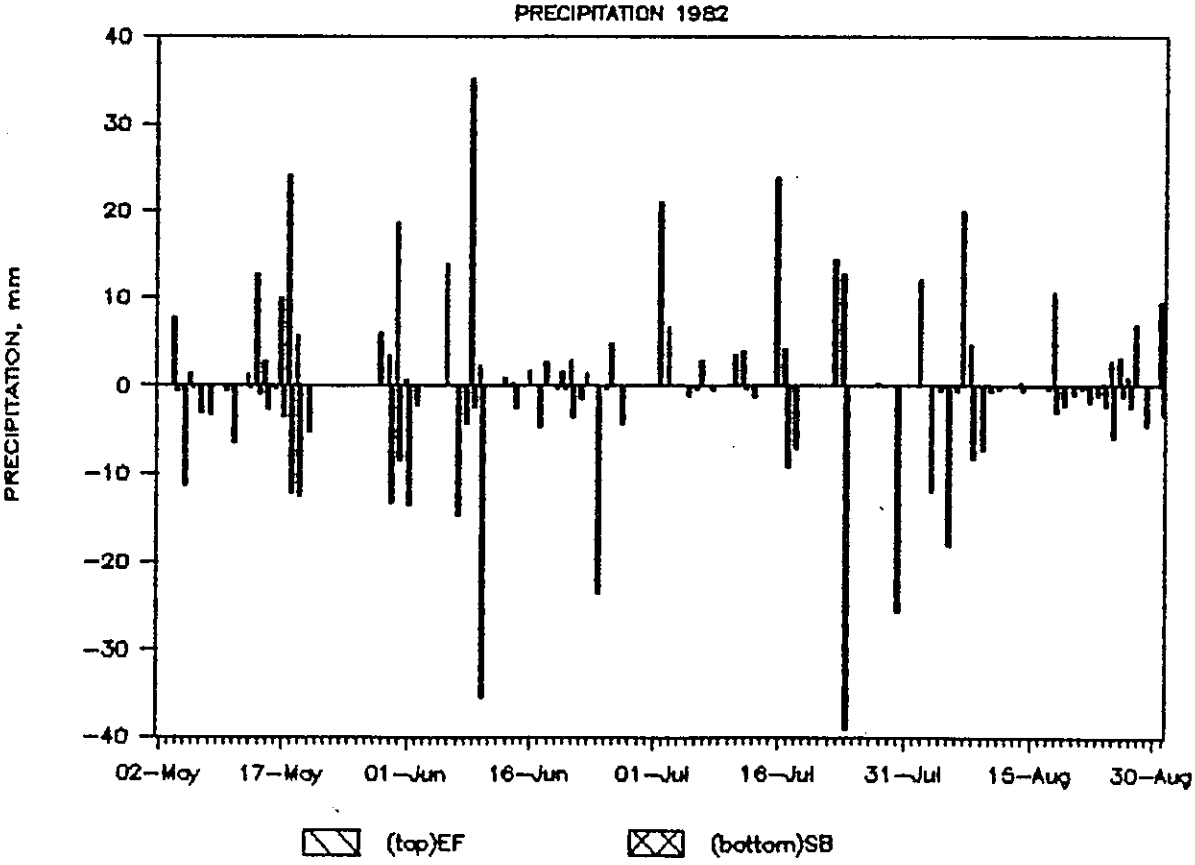


Figure 3K-1

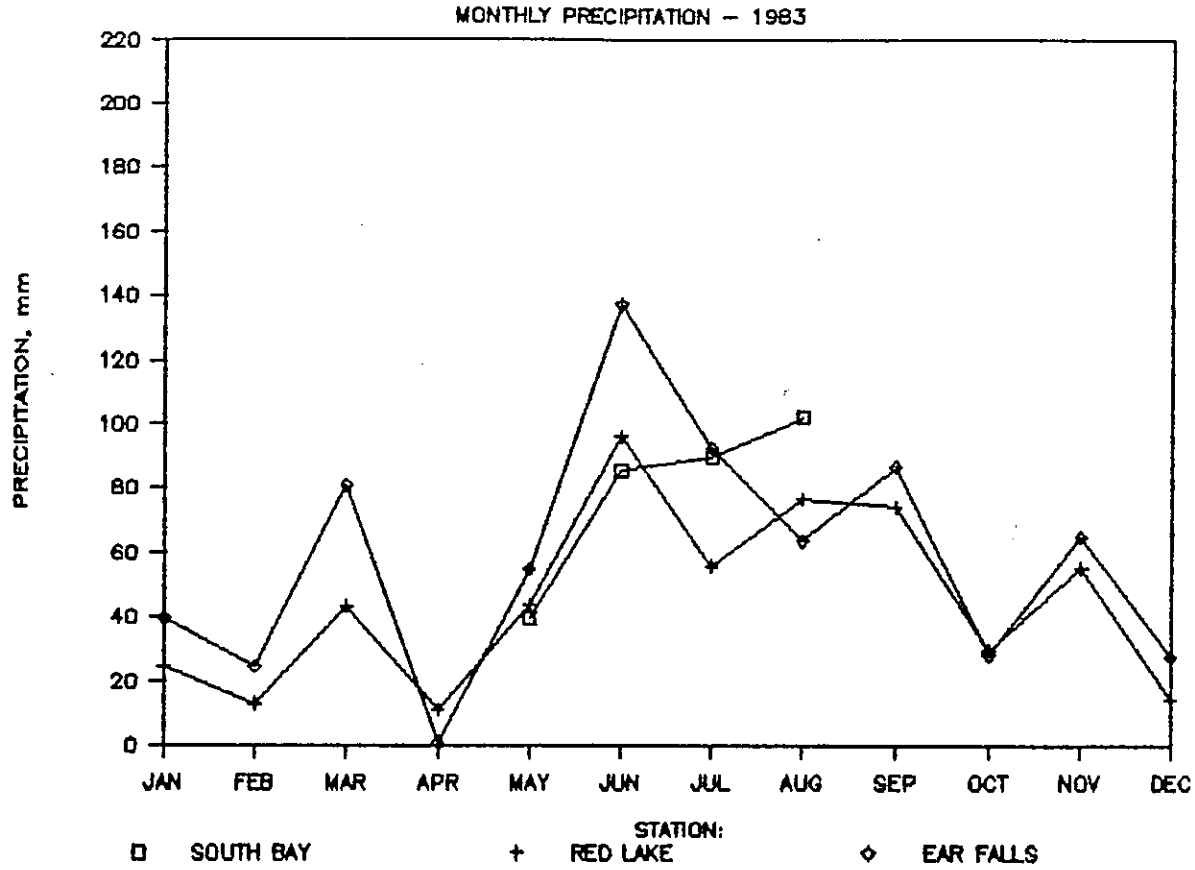


Figure 3K-2

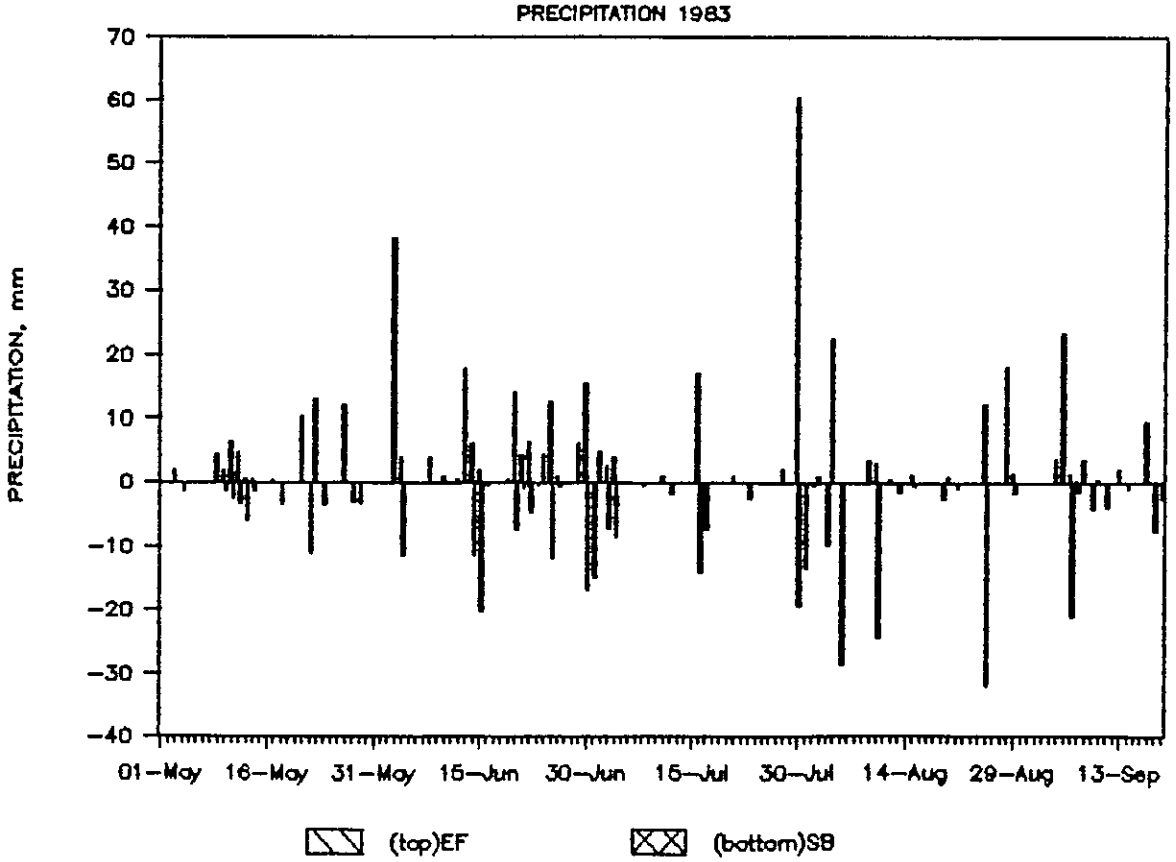


Figure 3L—1

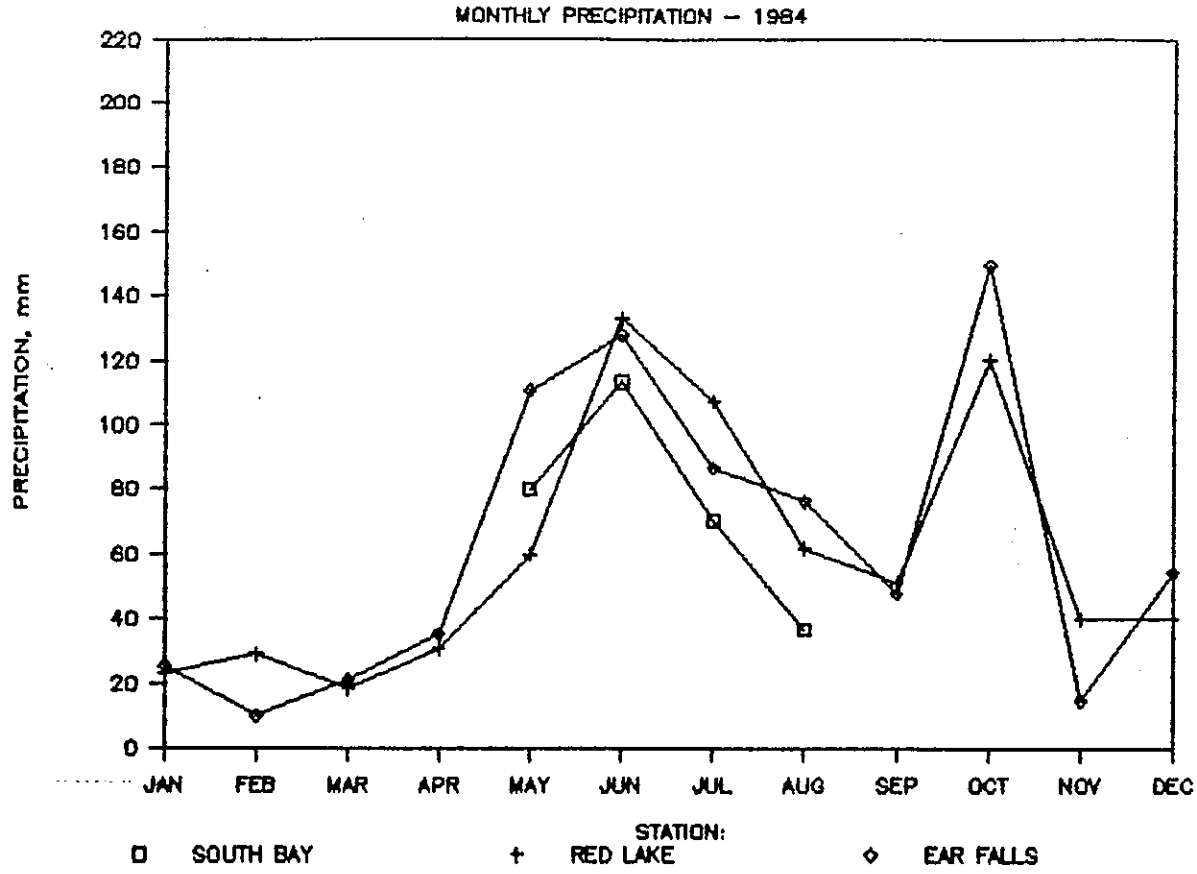


Figure 3L—2

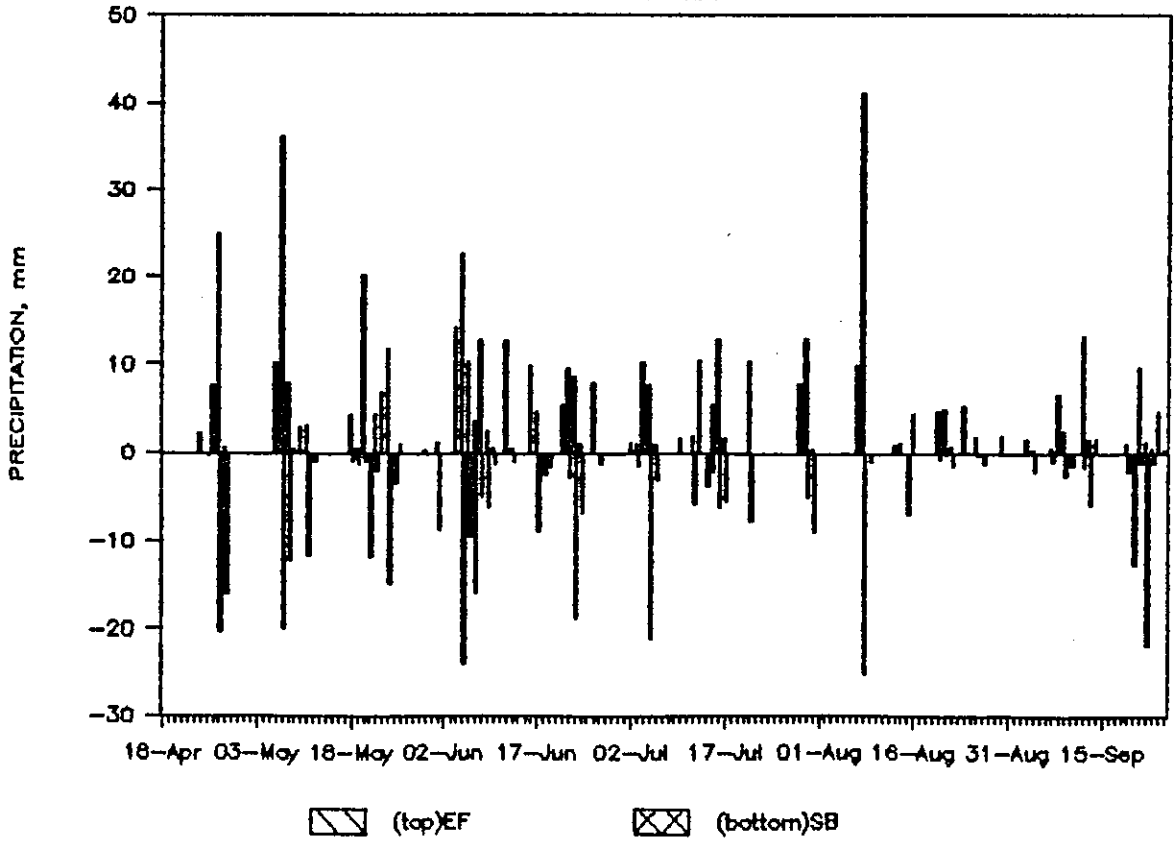


Figure 3M-1

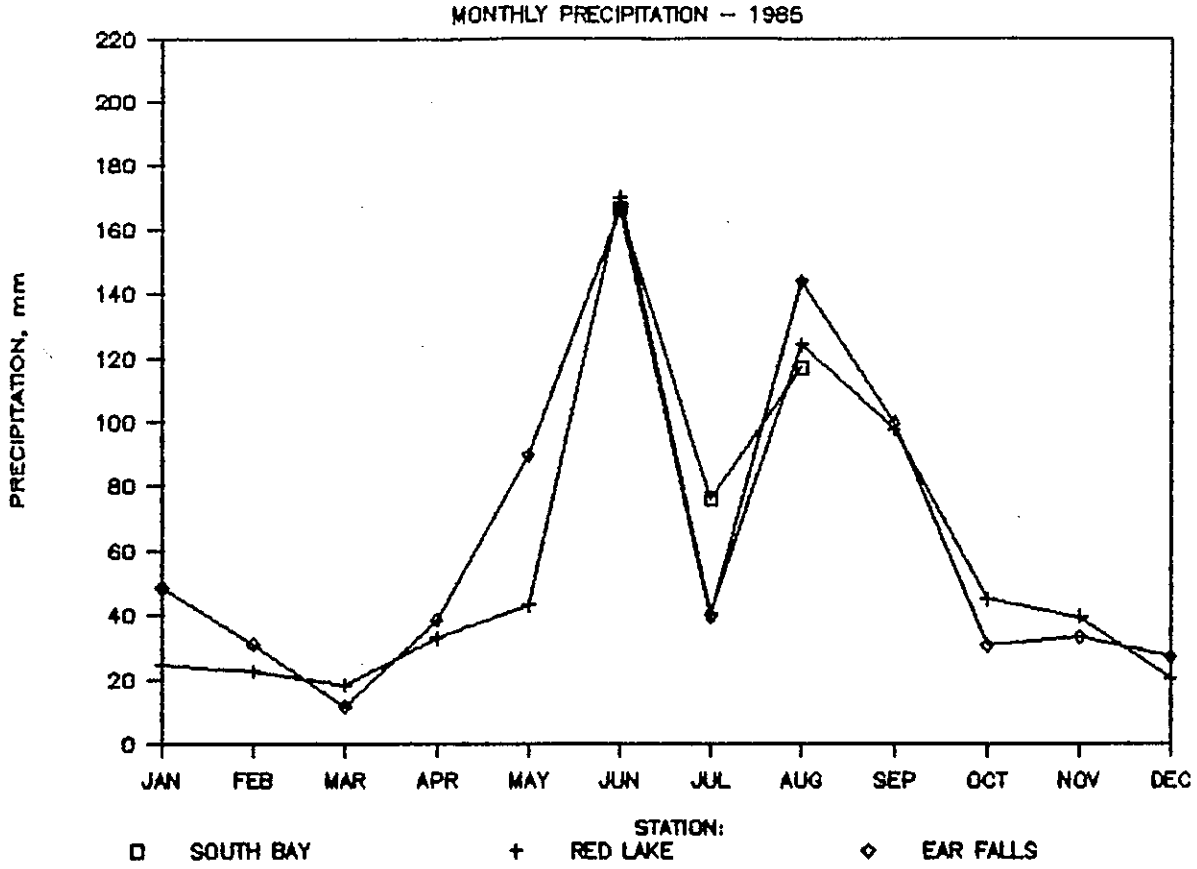


Figure 3M-2

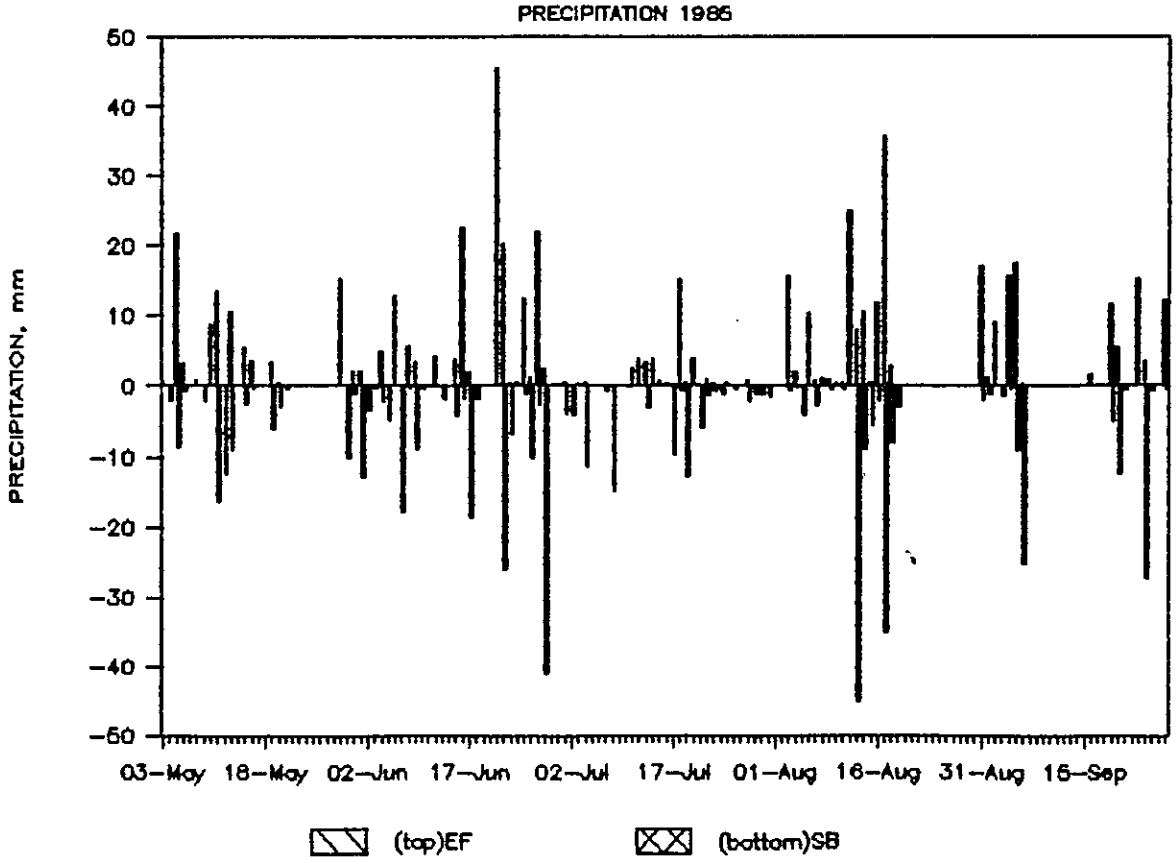


Figure 3N-1

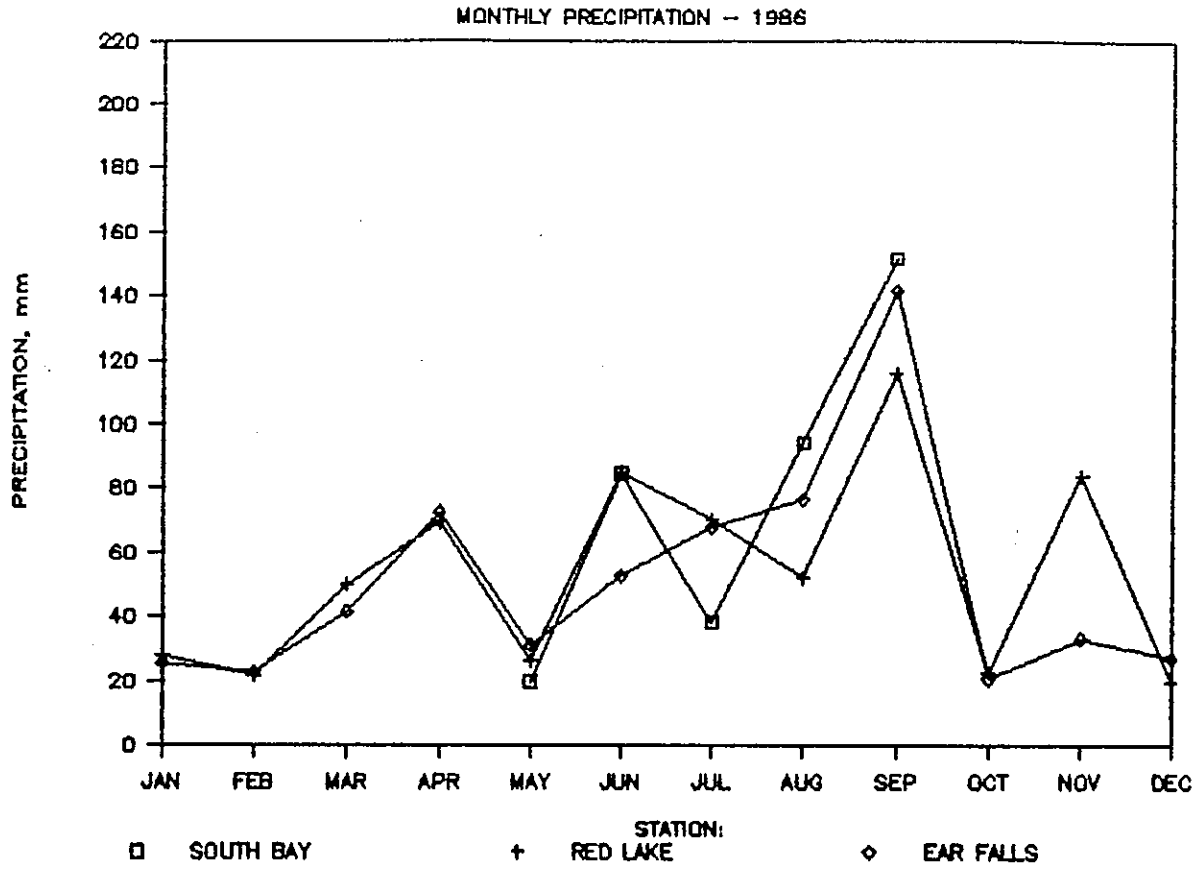


Figure 3N-2

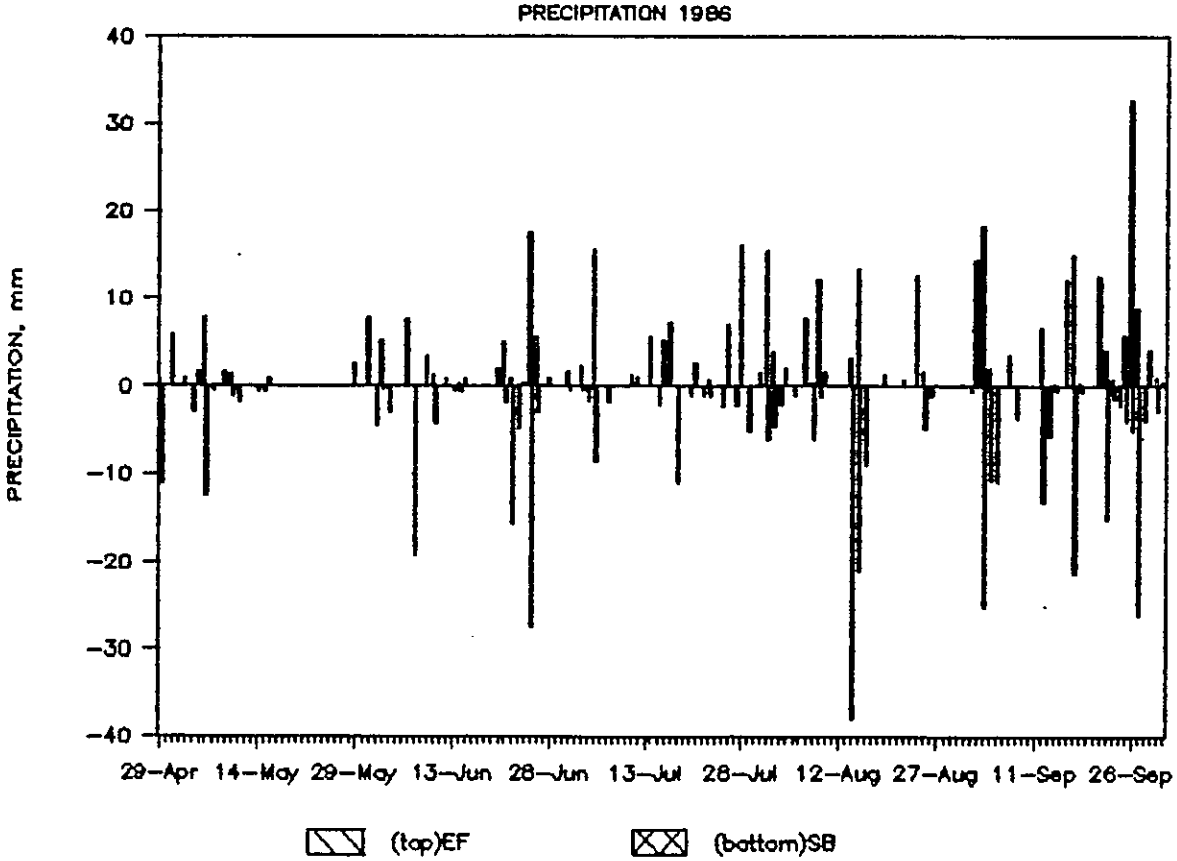


Figure 4A

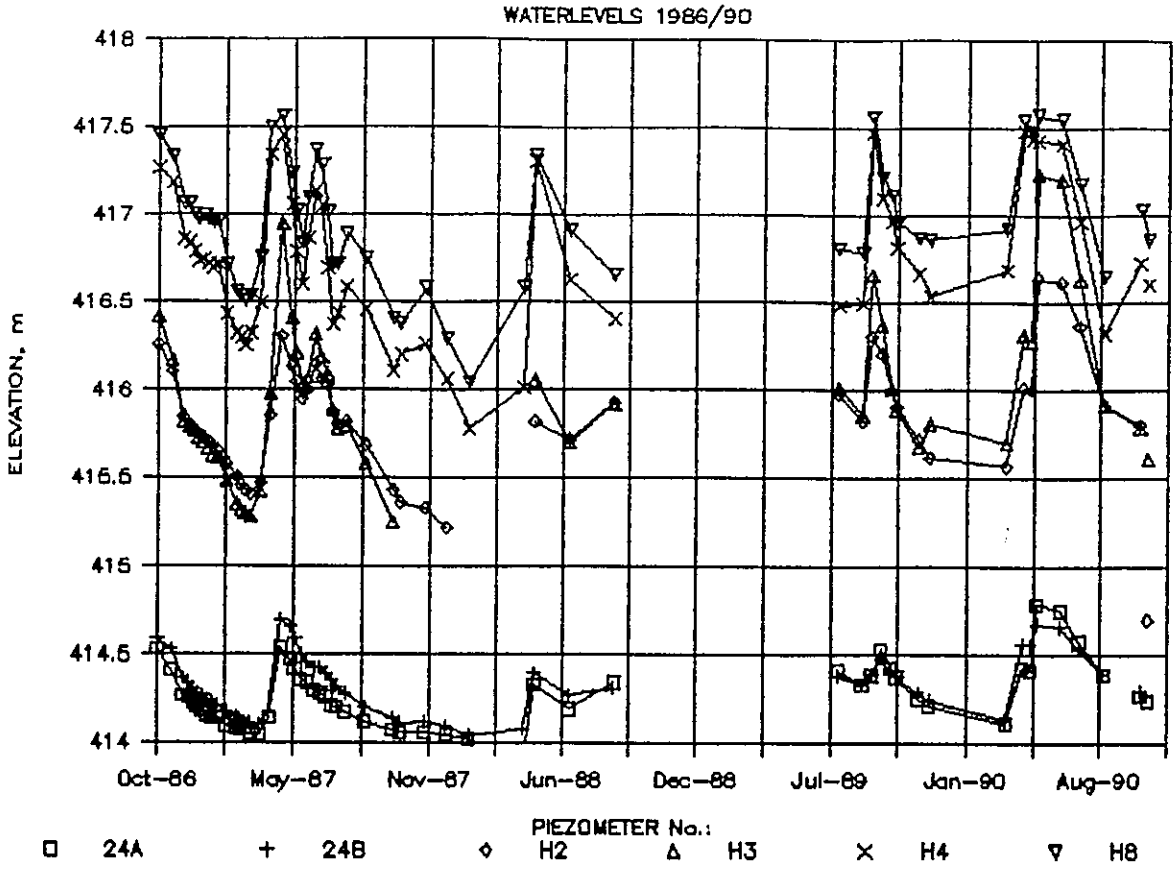


Figure 4B

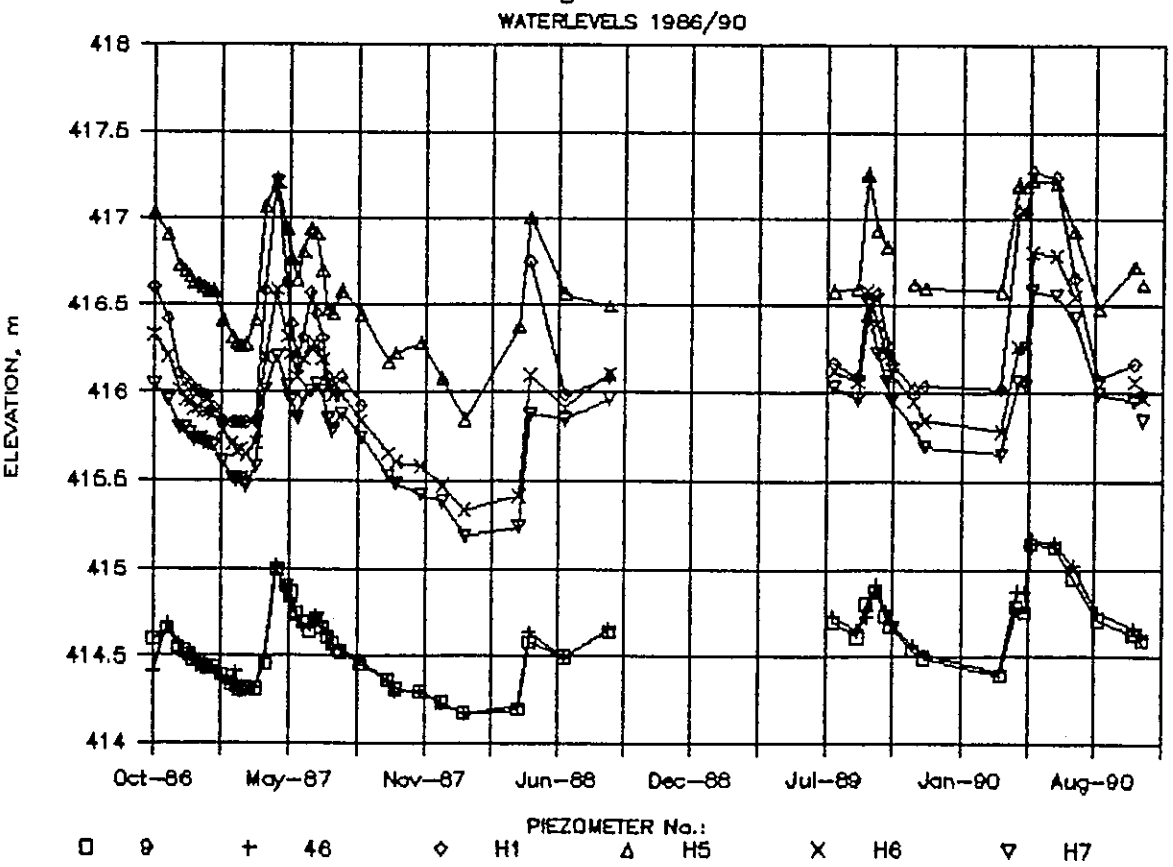


Figure 4C

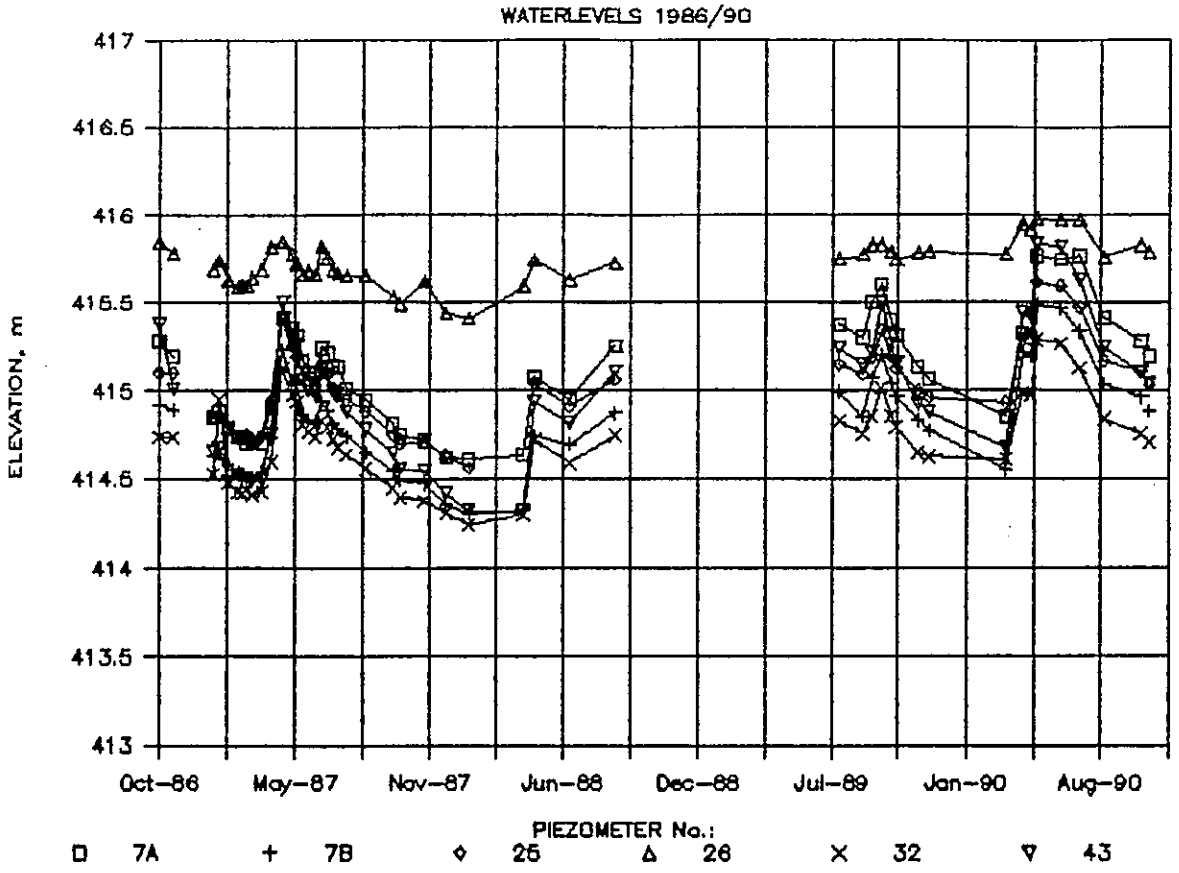


Figure 4D

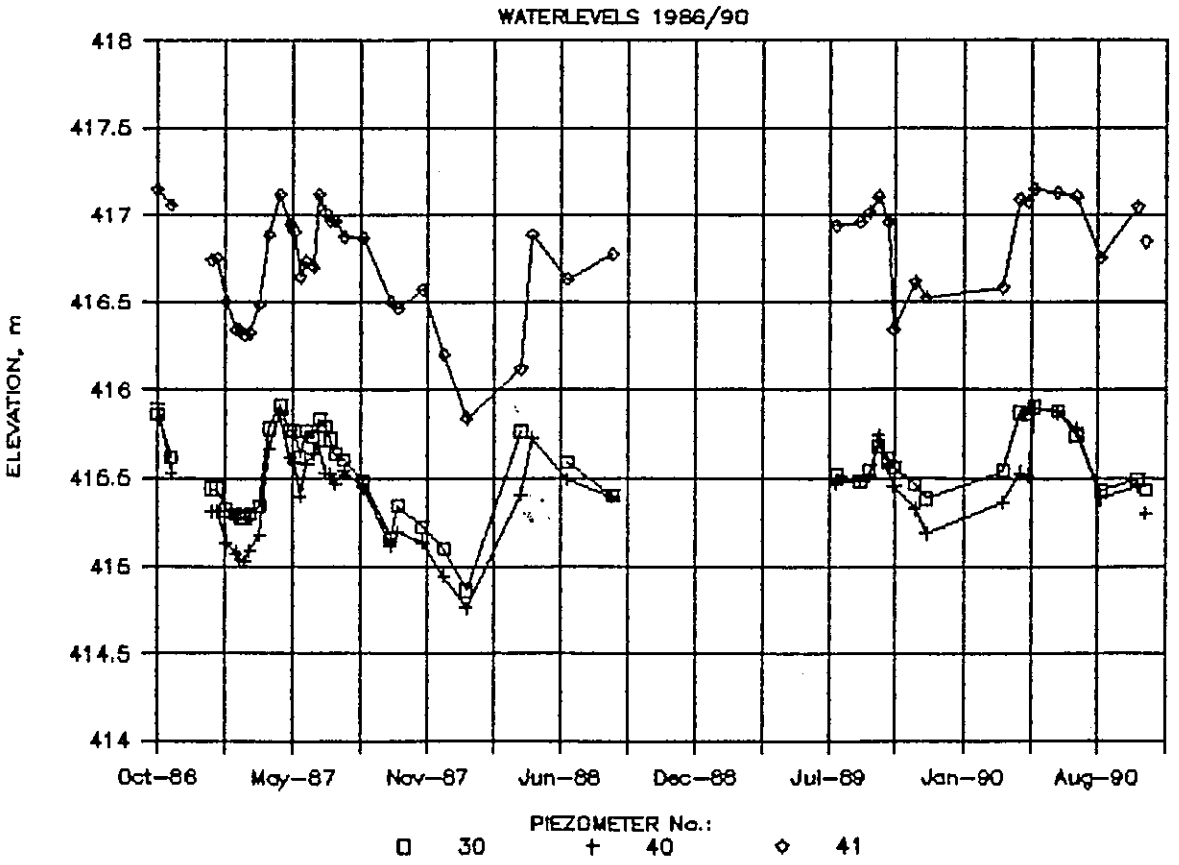


Figure 4E

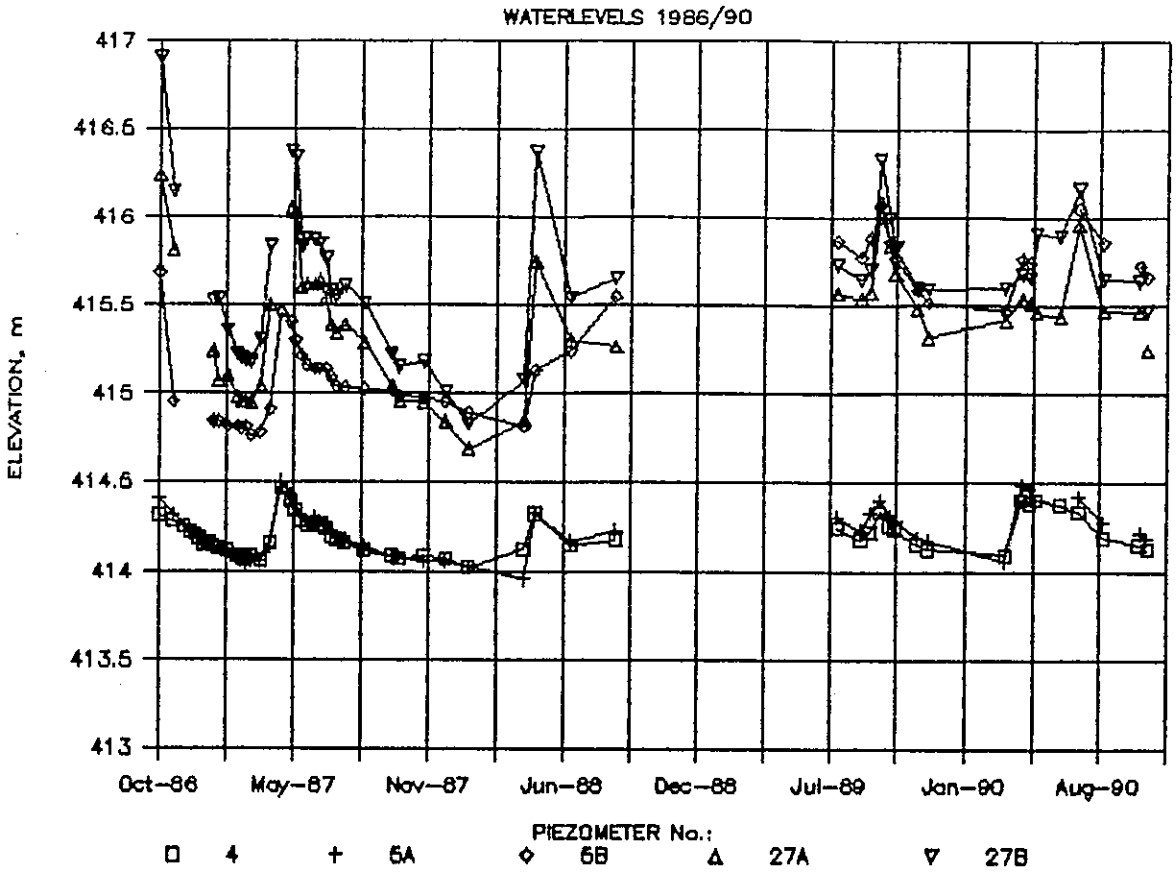

WATERLEVELS 1986/90
ELEVATION, m
417
416.5
416
415.5
415
414.5
414
413.5
413
Oct-86
May-87
Nov-87
Jun-88
Dec-88
Jul-89
Jan-90
Aug-90
PIEZOMETER No.:
4
5A
5B
27A
27B

FIGURE 5A

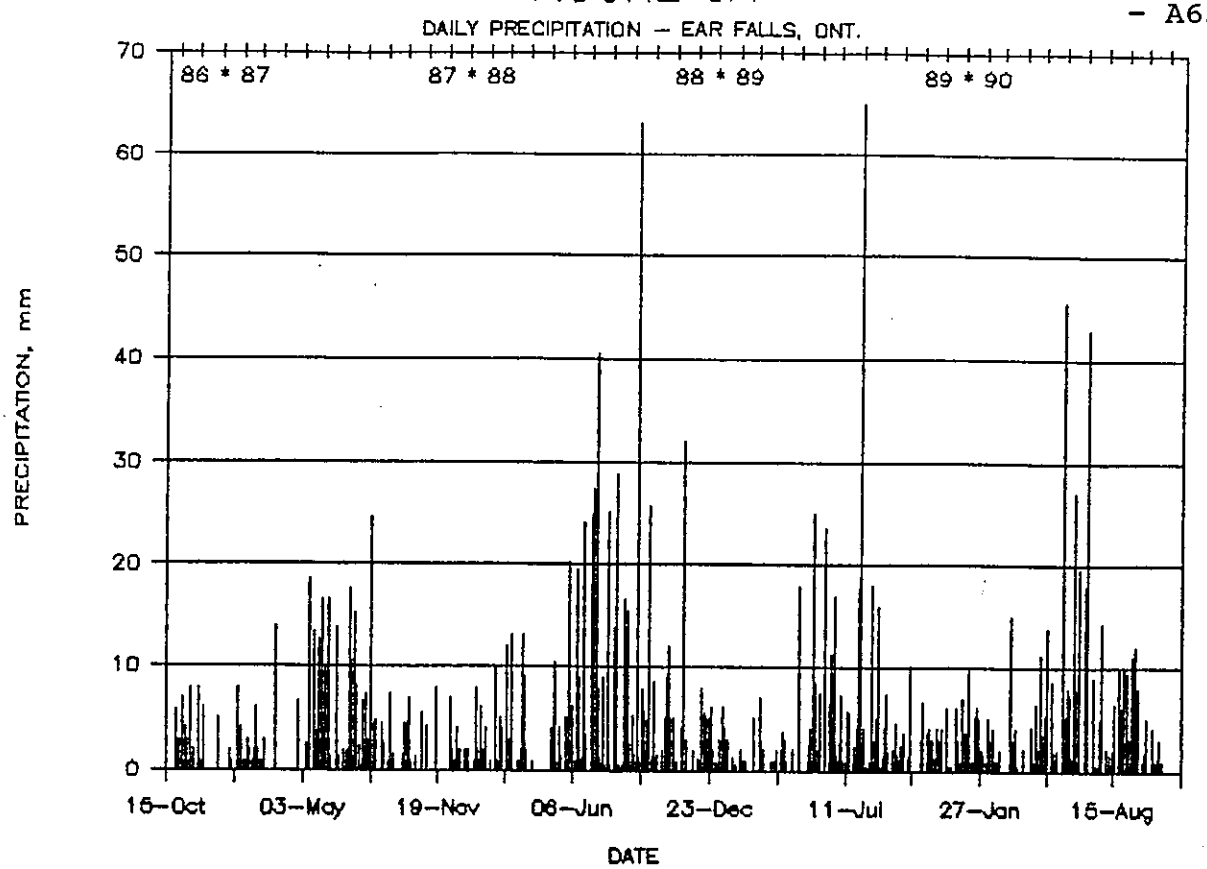


FIGURE 5B

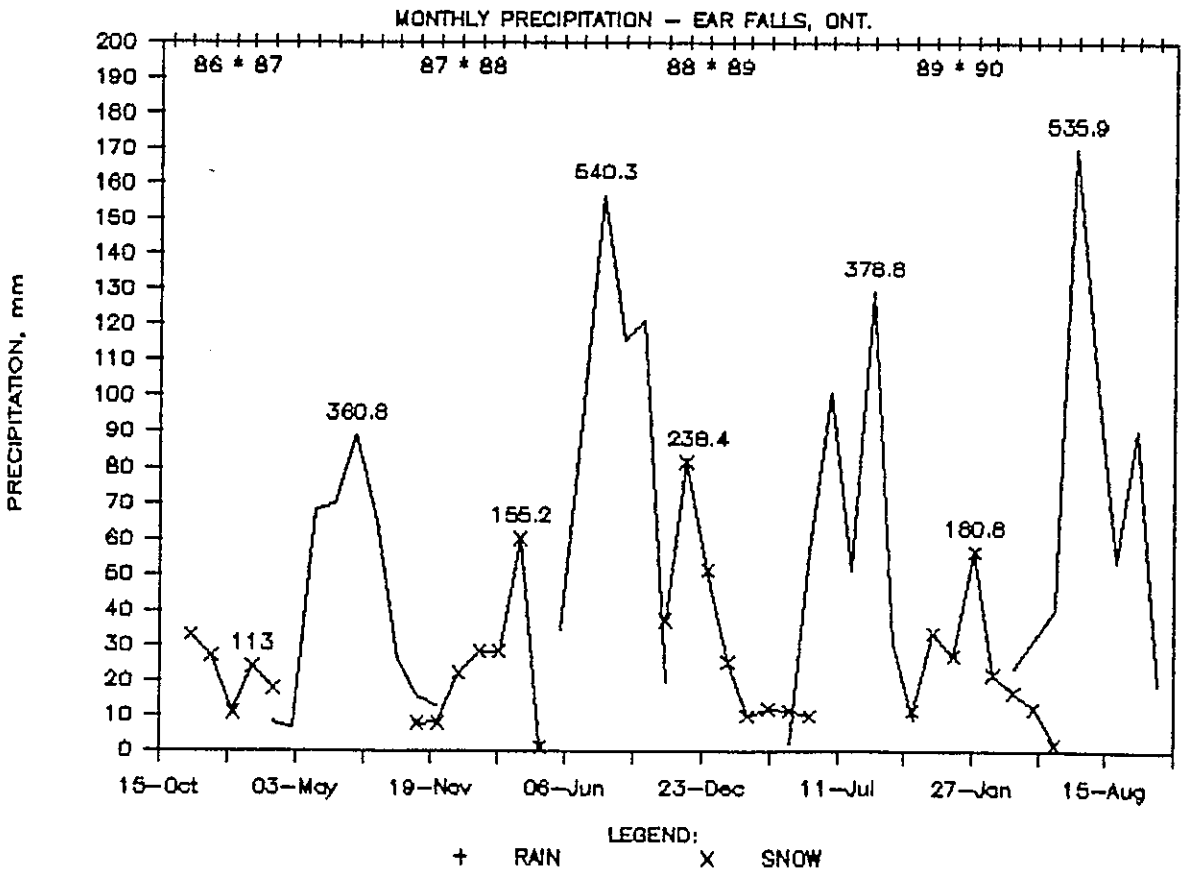


Figure 6A

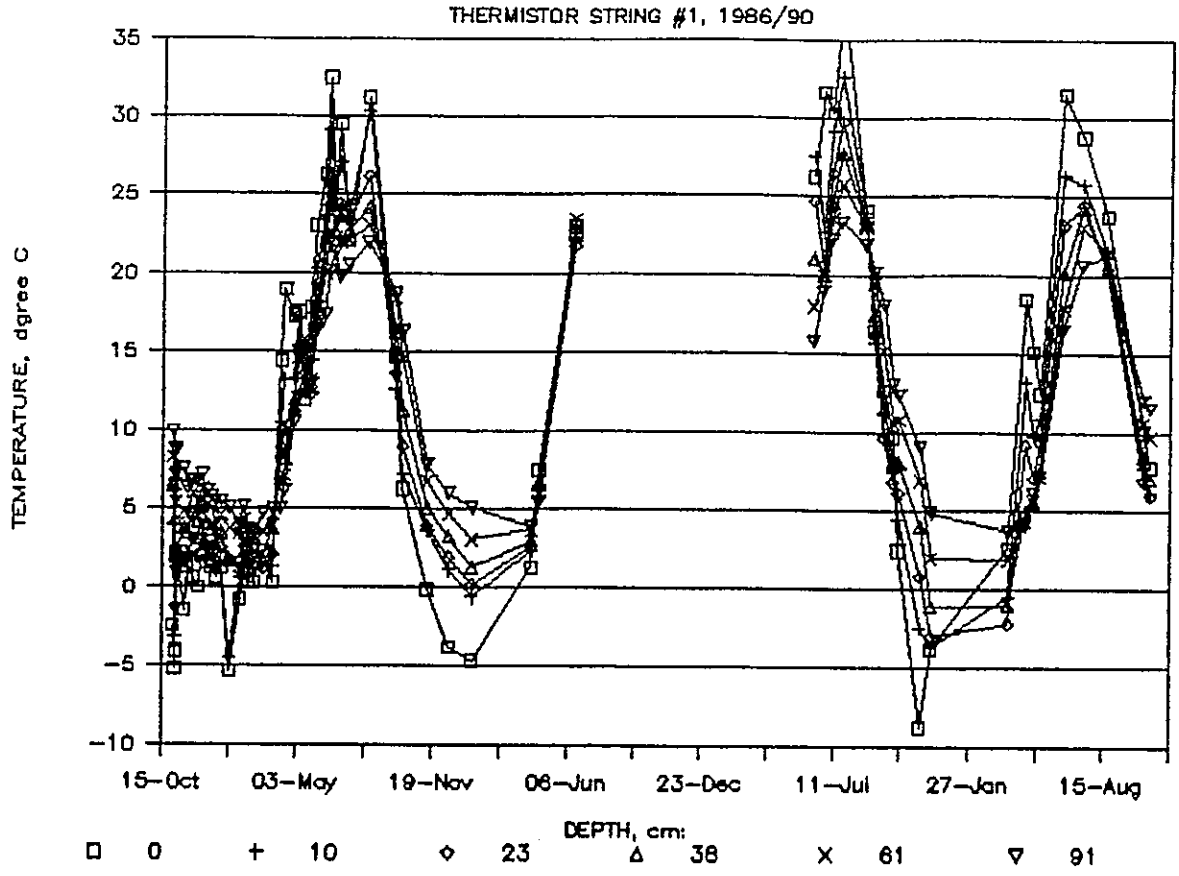


Figure 6B

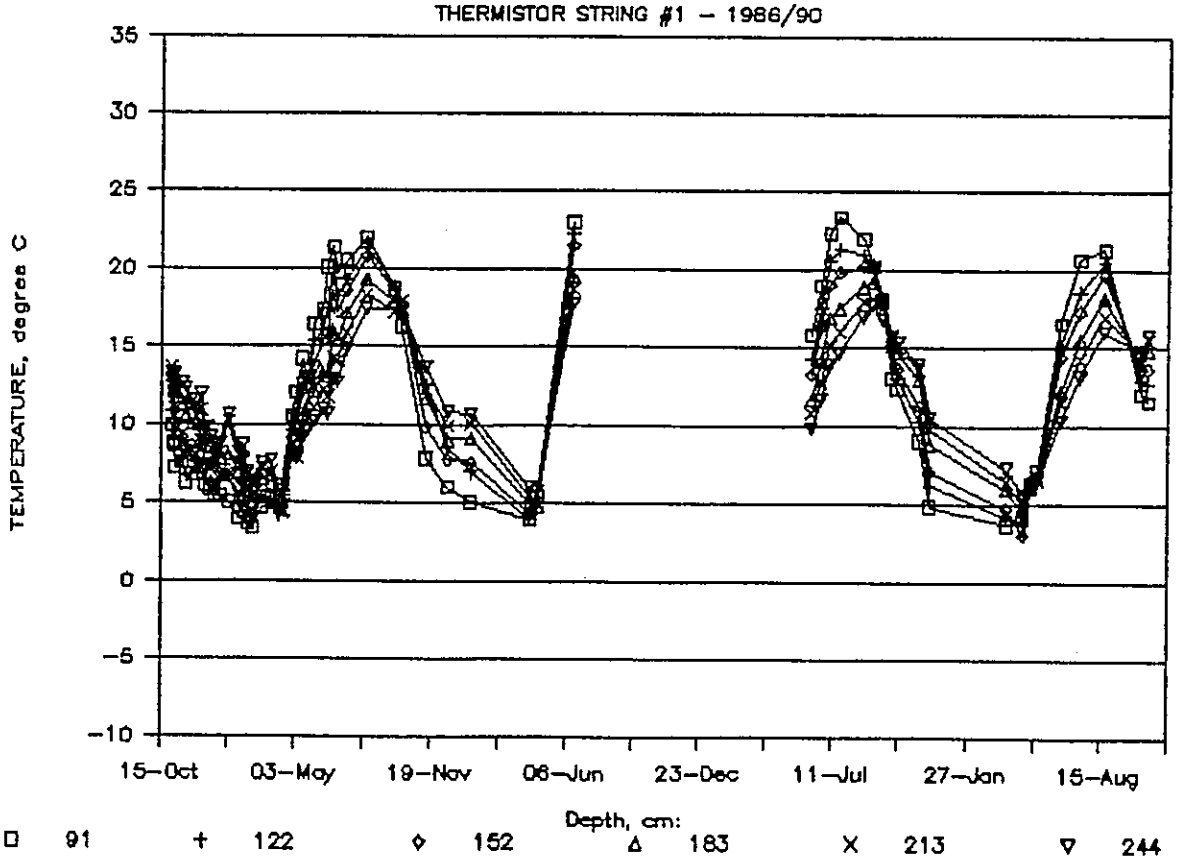


Figure 6C

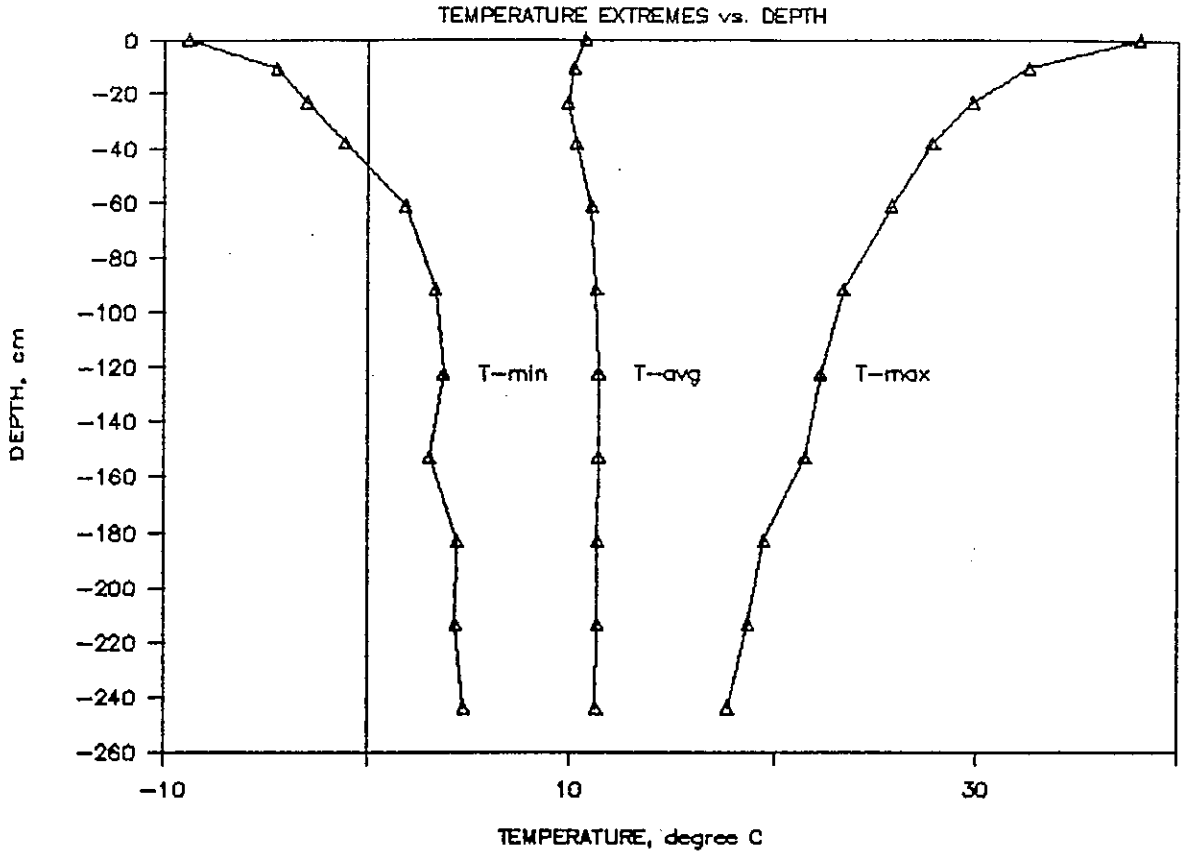


Figure 6D

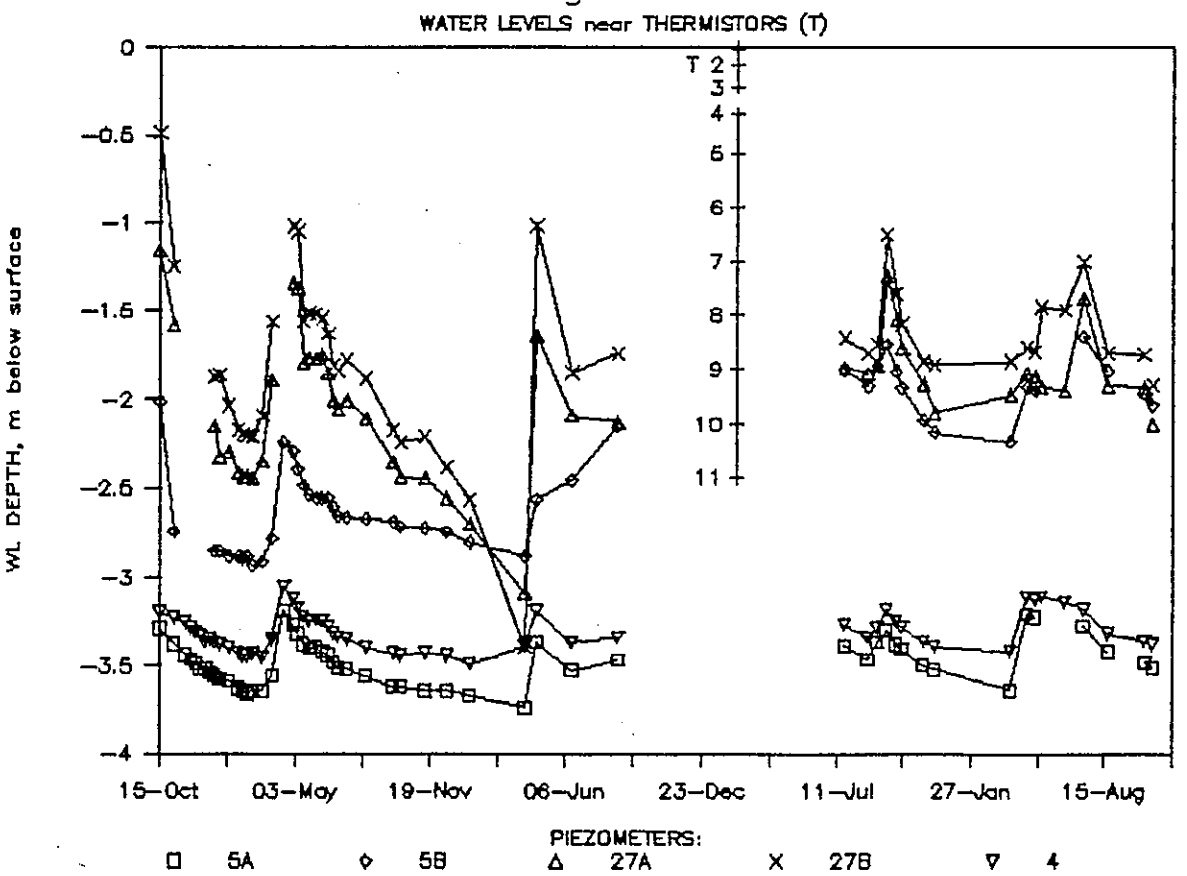


FIGURE 6E

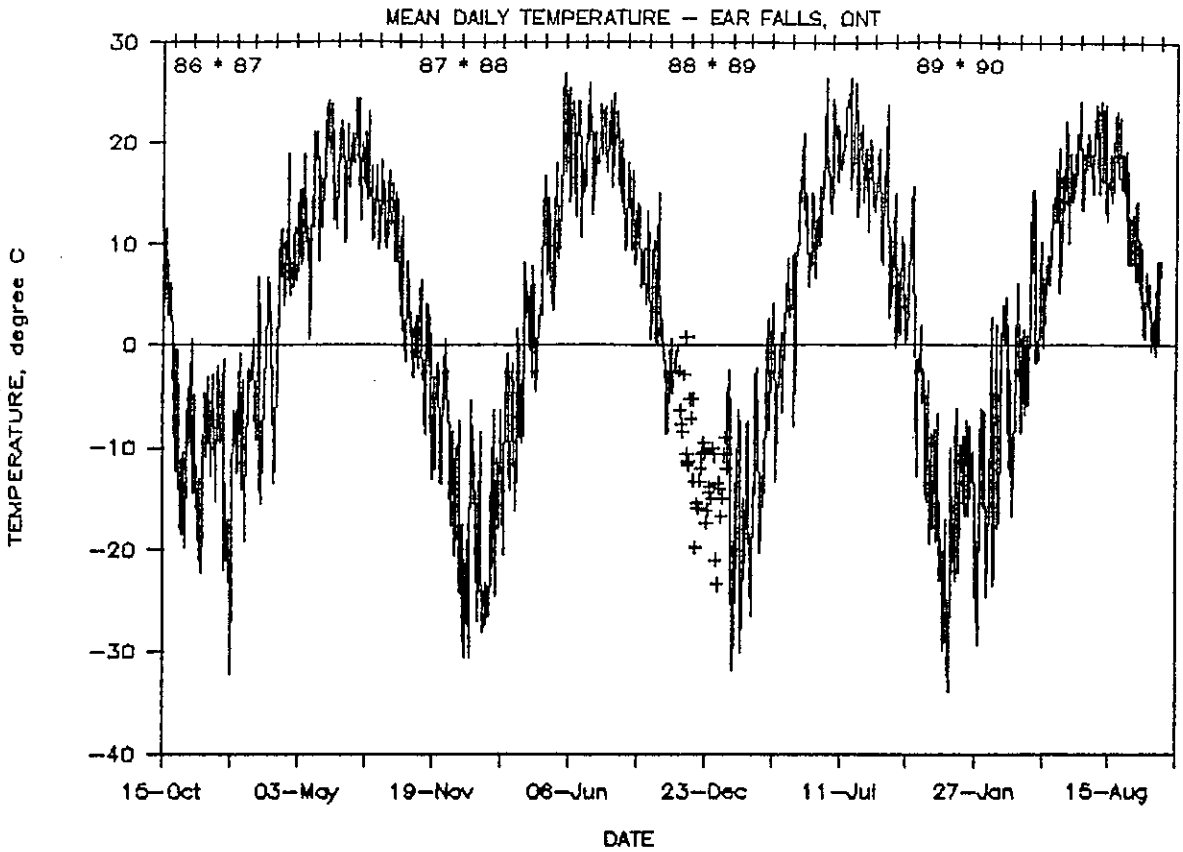

MEAN DAILY TEMPERATURE – EAR FALLS, ONT
86 * 87
87 * 88
88 * 89
89 * 90
30
20
10
0
-10
-20
-30
-40
TEMPERATURE, degree C
15-Oct
03-May
19-Nov
06-Jun
23-Dec
11-Jul
27-Jan
15-Aug
DATE

Figure 7A
pH, OCTOBER 1990

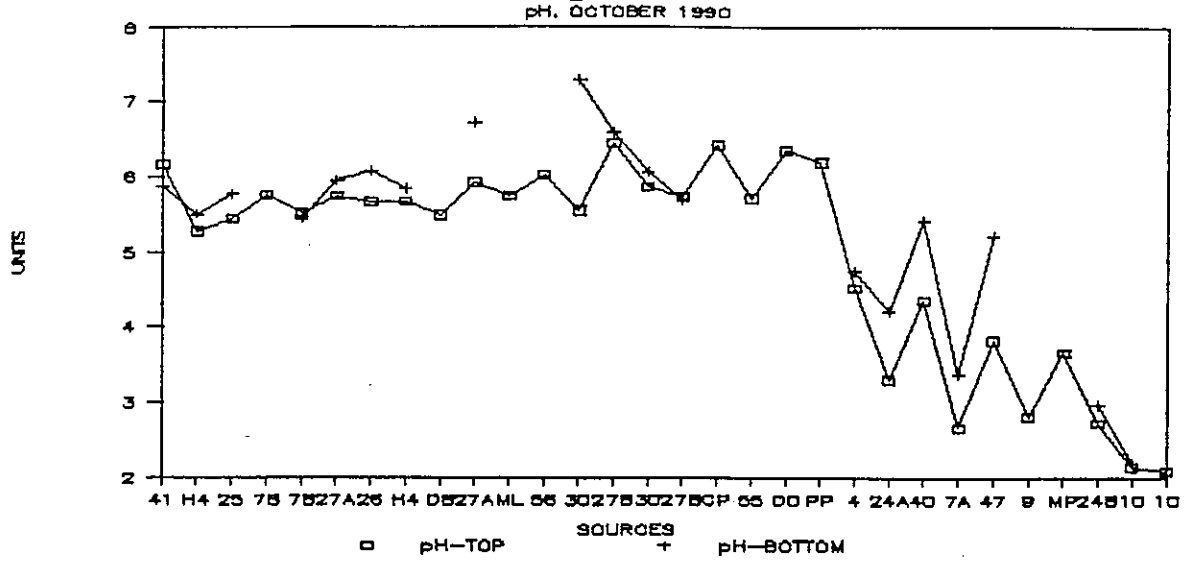


Figure 7B
pE, OCTOBER 1990

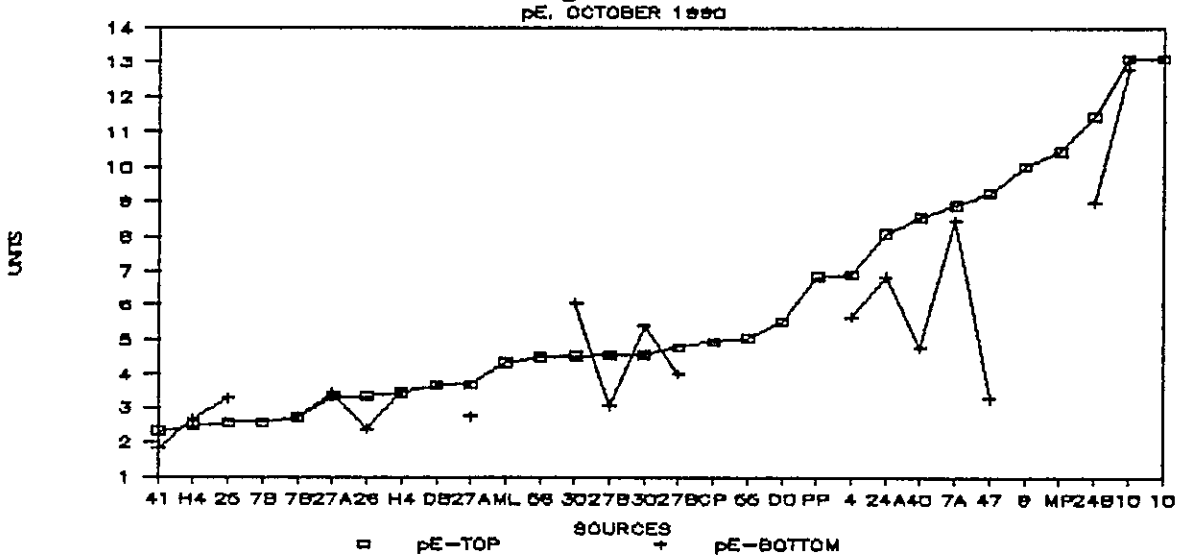


Figure 7C
CONDUCTIVITY, OCTOBER 1990

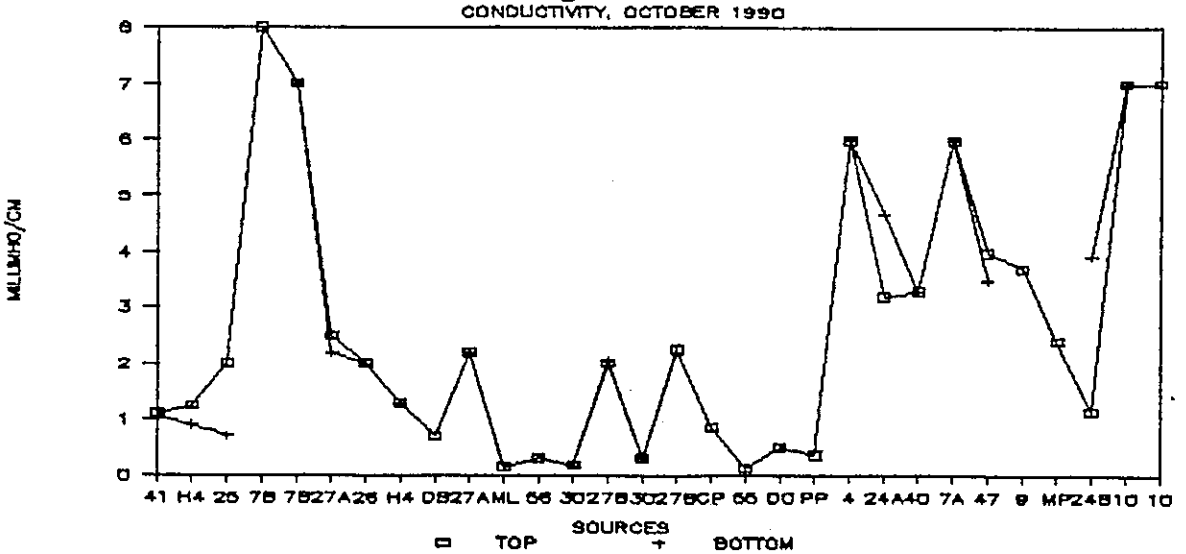


Figure 8A

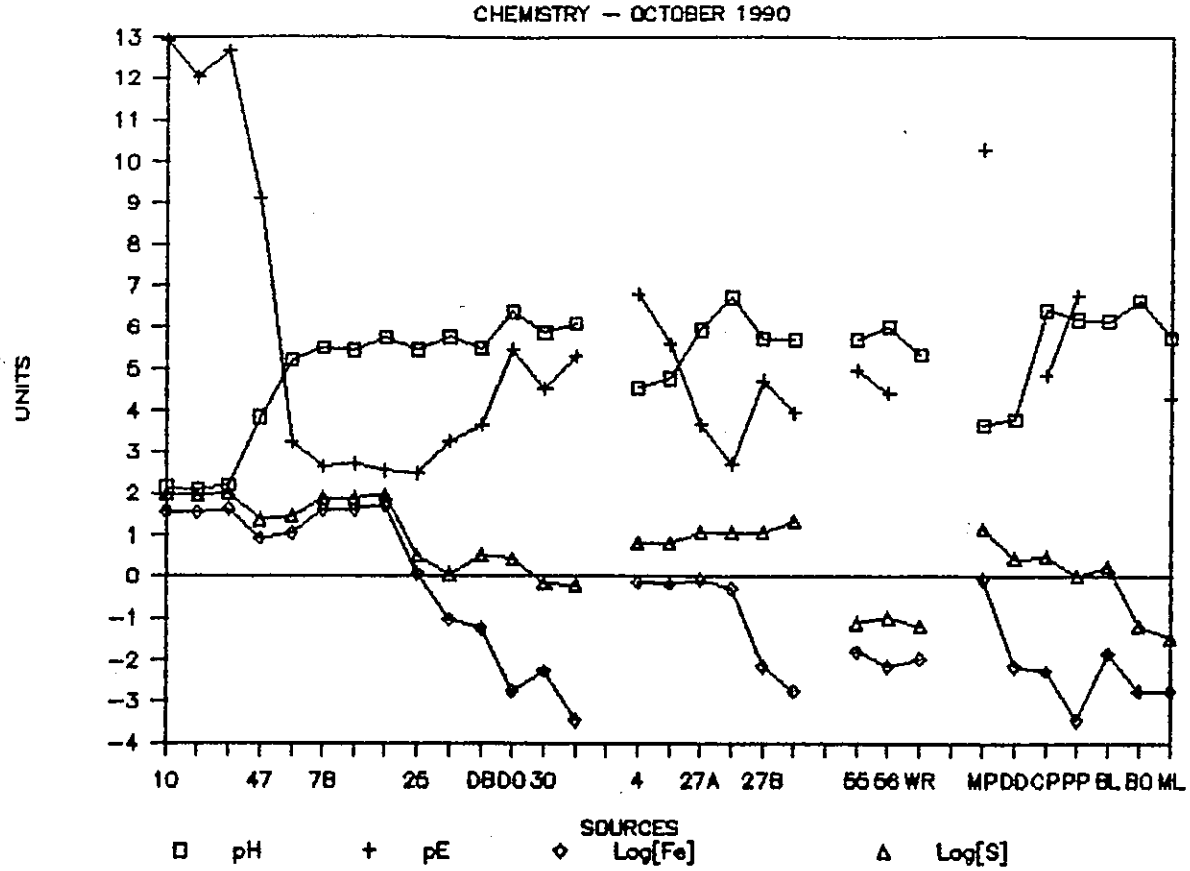


Figure 8B

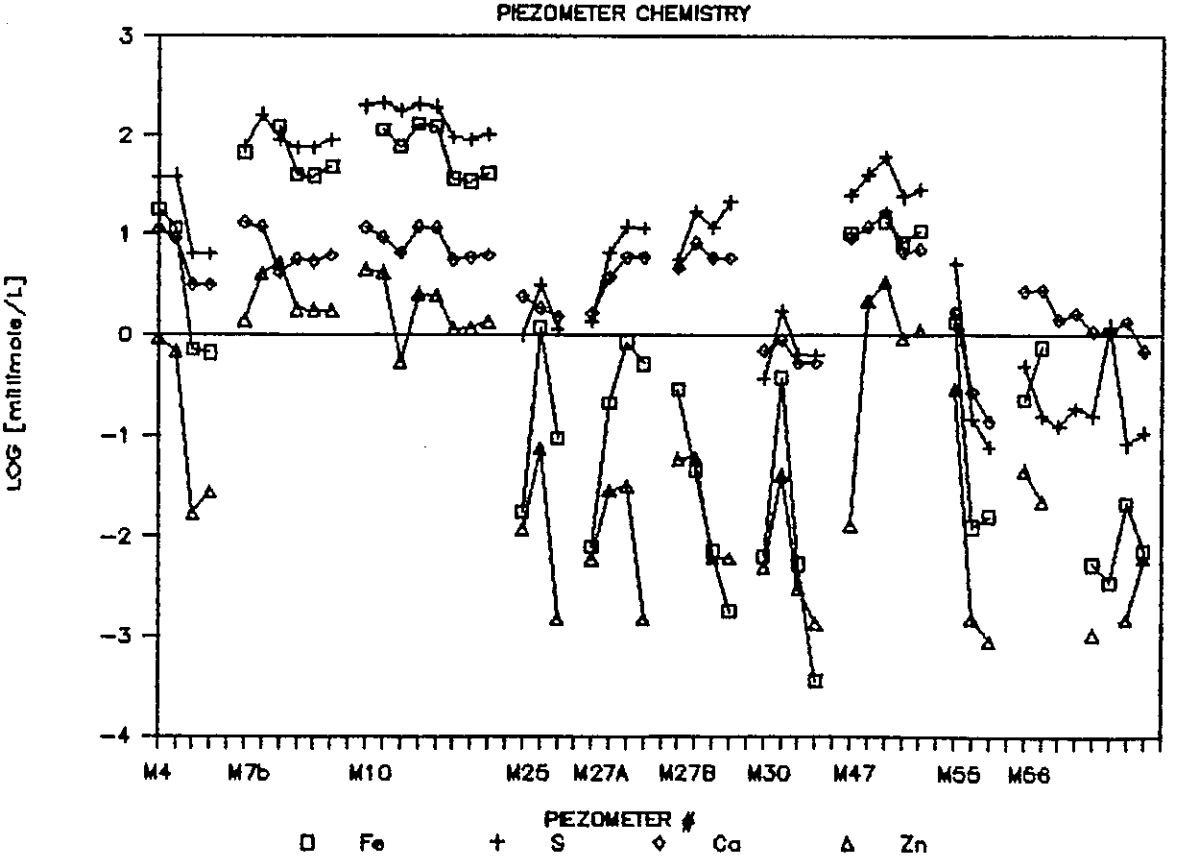
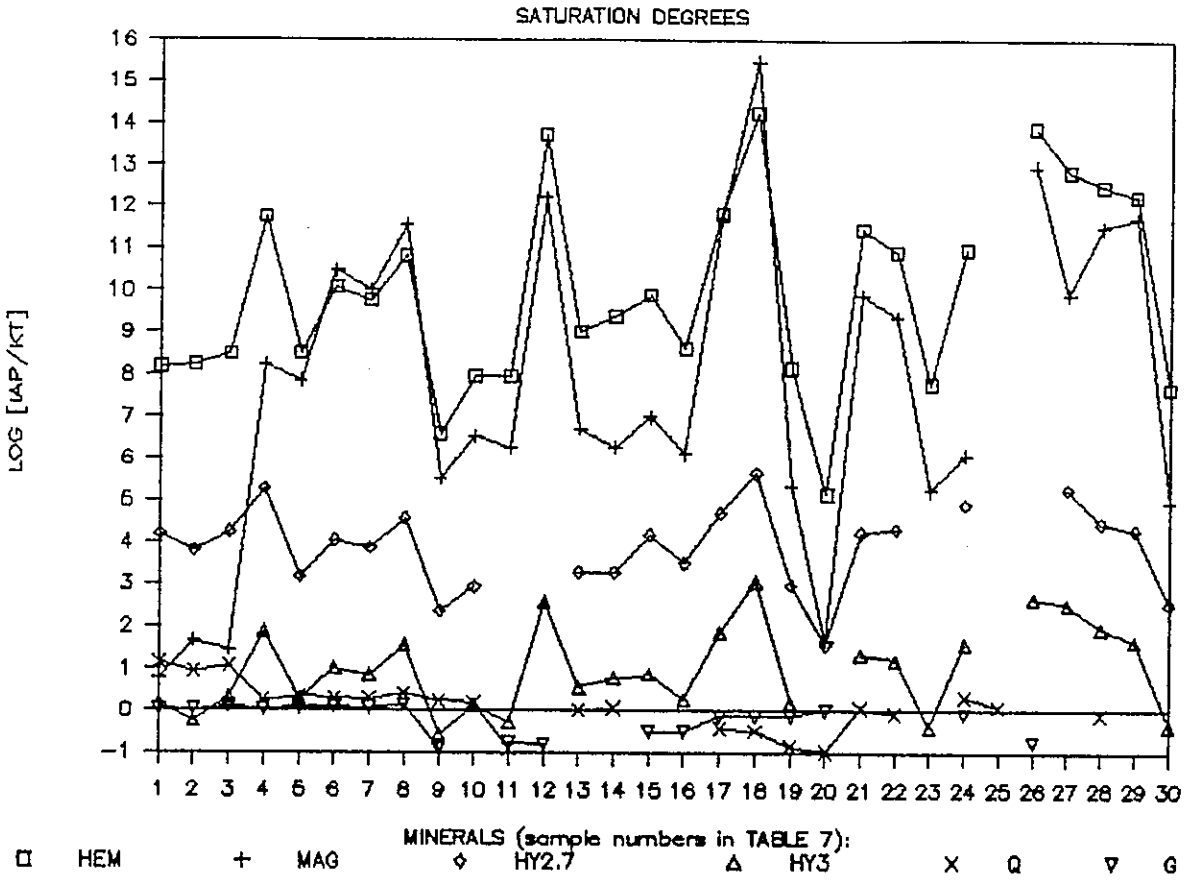


Figure 9


SATURATION DEGREES
LOG [IAP/KT]
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
−1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
MINERALS (sample numbers in TABLE 7):
HEM
MAG
HY2.7
HY3
Q
G

APPENDIX 3: Tailing sample descriptions

Sample	Description
2-24-1	Tailings: gray, silt size, 20-30% sulphides, unoxidized, well sorted, angular, thinly bedded-laminated; in places cross-cutting intrusive structures comprising brecciated sediment fragments. Flow structures. Sediment fragments, pale yellow - rust brown, oxidized, in a gray - pale yellow silt size matrix. At contact, 0.1-0.5 mm thick zone with intense dark brown Fe oxide staining/precipitation, intruding unoxidized host rock. Tailings: gray, pred. silt size, 10-40% sulphides; within silt range various degrees of sorting resulting in minature lenses and laminae with different silt sizes. Festoon bedding (micro ripples?) and/or soft sediment deformation. Coarser silt fraction generally intensily oxidized, yellow brown. In places relative assive laminae and thin beds of Fe oxide with floating to loosely packed very fine - ine grained rock fragments and grains (pred. quartz). Overall: sequence of thinly bedded - laminated silt (pred.) and very fine grained size tailings. Very fine grained tailings and coarser silt beds/laminae intensly oxidized and partially cemented with yellow brown iron oxide. Intraformational breccia: soft sediment deformed, fragments are gray (unox.), pale yellow to rust brown (ox.). Matrix primarily pale yellow. The oxidation of fragments pre-dates the deformation.
2-24-2	Tailings: gray, silt size, > 50% sulphides, unoxidized, thinly bedded to laminated. In places slightly less sulphide rich beds and consequently coarser silt size grains.
2-24-3	Tailings: gray - rust brown, distribution of colour is grain size controlled. The tailings are thinly bedded, approximately 1 cm thick, and bounded by thin beds of rust brown oxidized very fine grained, quartz-rich beds. The tailing beds are silt to silt-very fine grained in size, 30-40% sulphides with a smattering of very fine grained rock/mineral particles. Thinly bedded - laminated, sorted - well sorted. Occasionally laminae comprising very fine quartz-rich grains (wind blown?). Immediately adjacent to quartz-rich beds a zone, < 1mm thick, is present with moderate oxidation. The oxidation of the sand beds bounding the tailing bed extends into the unoxidized tailing bed and shows zonation. The colour changes from rust brown-brown (sand) to pale yellow brown to grayish pale yellow brown to gray (tailings).
2-24-4	Tailings: as 2-24-3, thinly bedded - laminated, slightly more heterogeneous and variable. Occasional laminae of "clay size" Fe oxide (total alteration of

sulphide layers?). In places laminae comprising very fine grained non-sulphide particles alternating with laminae of silt size sulphides (> 50%).

M27-1 Tailings: brown, fine to medium grained, sulphides (30-40%), rock fragments, and grains of quartz &feldspar; Fe oxide stained; friable, slightly cemented in places.

M27-2 Tailings: light gray, unoxidized, silt size (pred.), < 5% sulphides, predominantly quartz. Thinly bedded to laminated with interbeds of silt to very fine grained size tailings, yellow to pale yellow, oxidized. At contact between coarser oxidized beds and unoxidized silt size tailings irregular pale yellow "clay size" bed of Fe oxide. (Depositional? Precipitate?). Soft sediment deformation with occasionally flame structures. Irregular, pseudo festoon type, pale yellow to yellow brown oxidation pattern in unoxidized light gray silt size tailings.

M27-3 Tailings as in M27-2. In places well cemented white - gray patches (gypsum? silica?), Numerous small cavities, < Imm in diameter, enclosed gas bubbles?

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SAMPLE 1M-244

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4925 Dufferin Street
Downsview, Ontario M3H 5T6
Tel: (416) 667-7742 Fax: (416) 667-7799

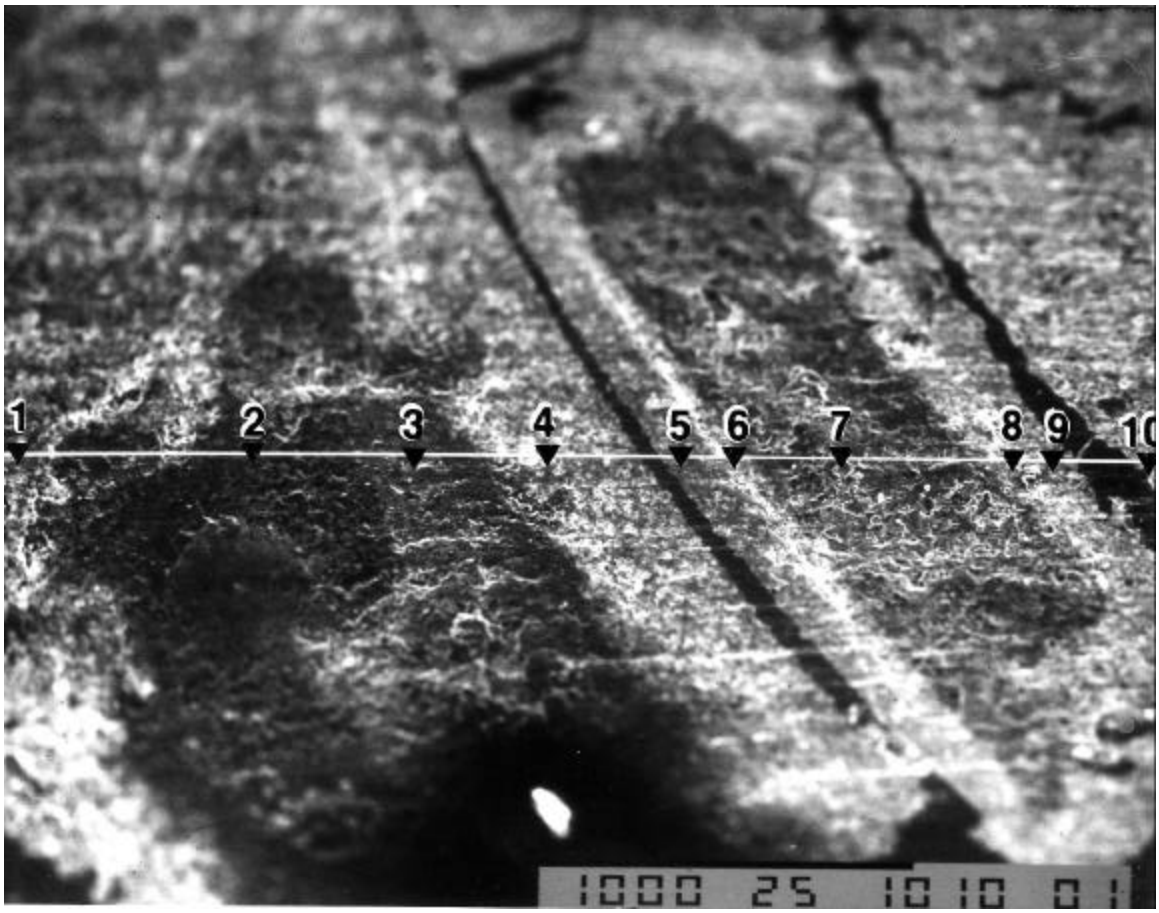

Figure 1. SCANNING ELECTRON MICROGRAPH OF SAMPLE 1M-244. Ten different areas (marked 1-10 along the white line on the picture) were analyzed by EDS.

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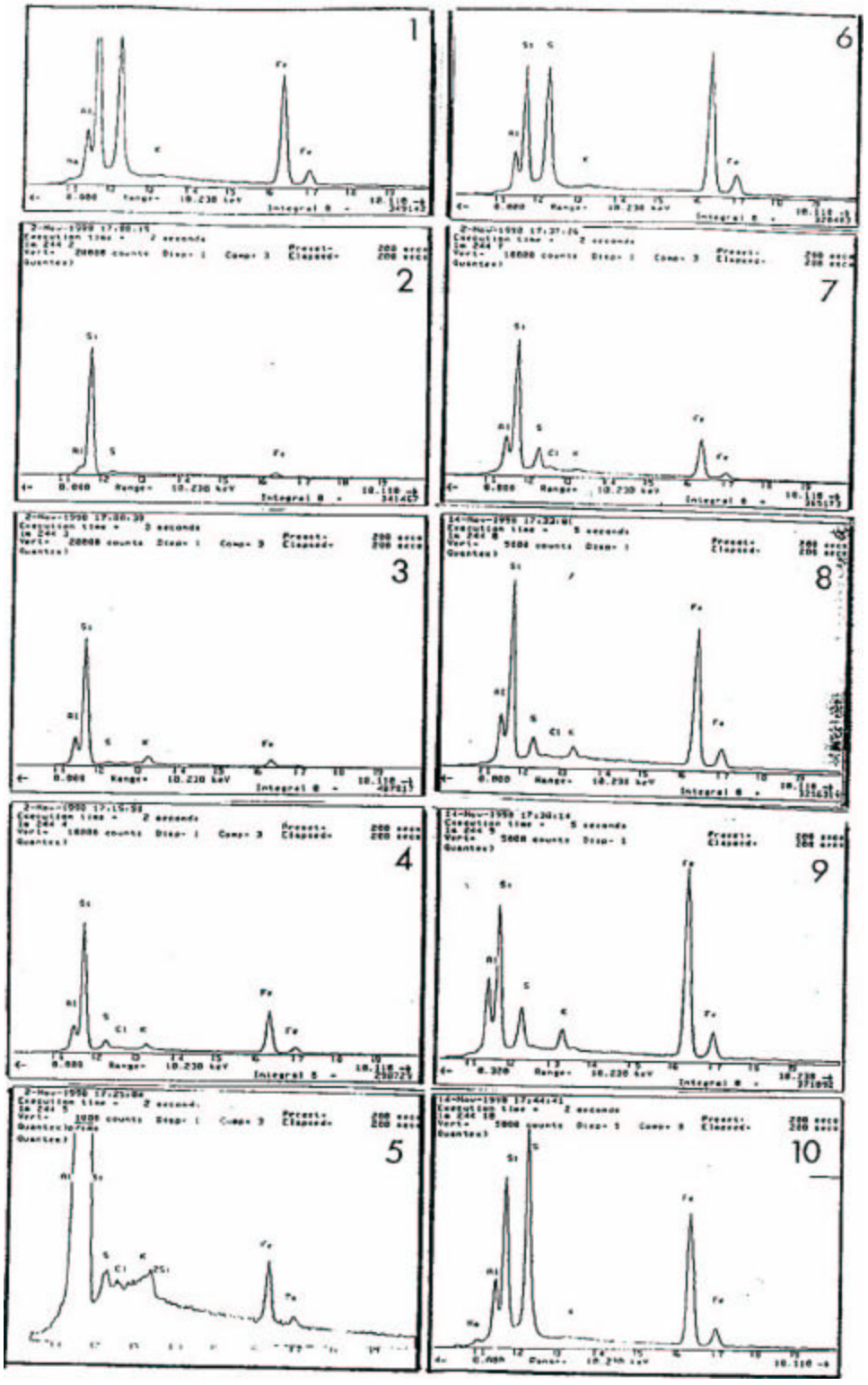

FIGURE 2. Energy dispersive X-ray analysis of area marked 1-10 on Fig. 1.

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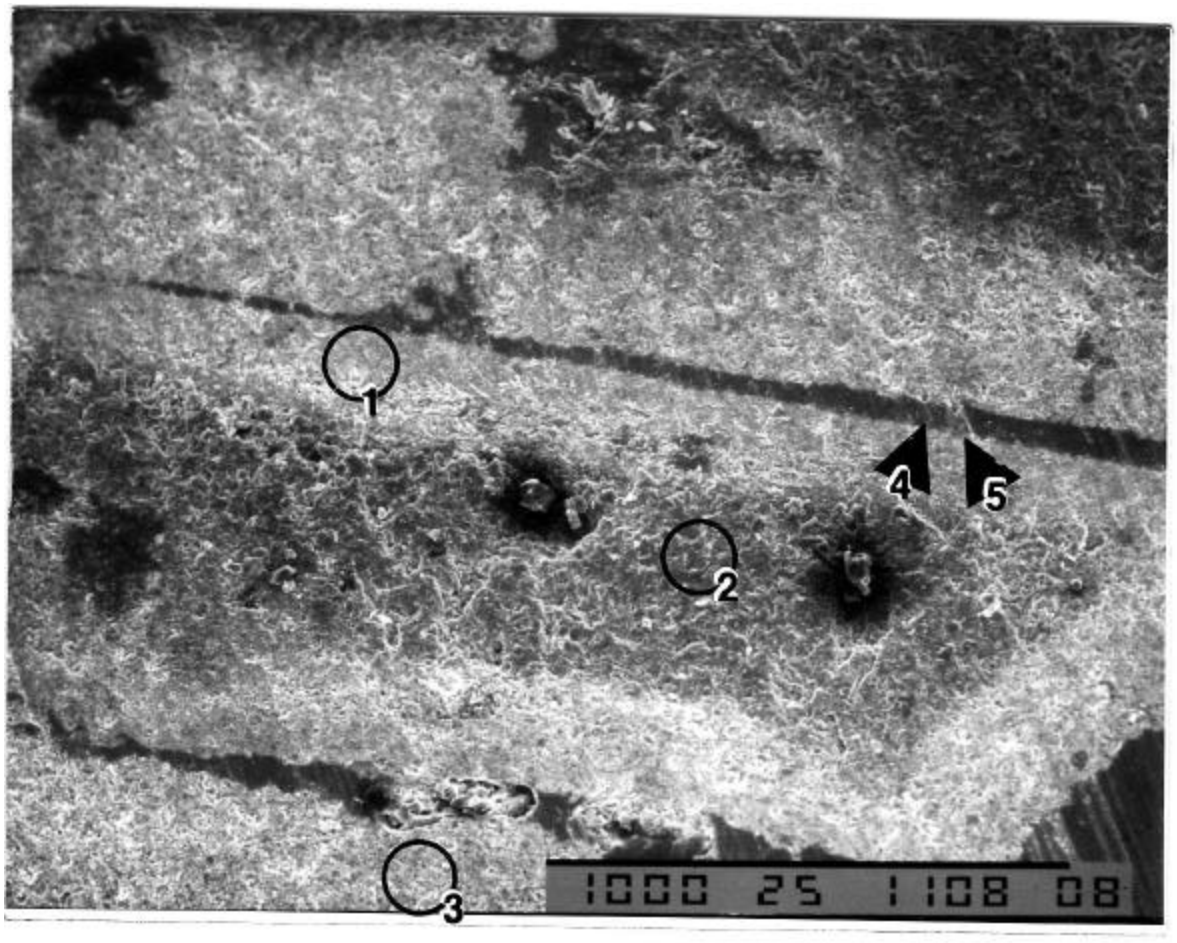

Figure 3. SCANNING ELECTRON MICROGRAPH OF SAMPLE 1M-244. Areas analysed with EDS are marked 1 through 5.

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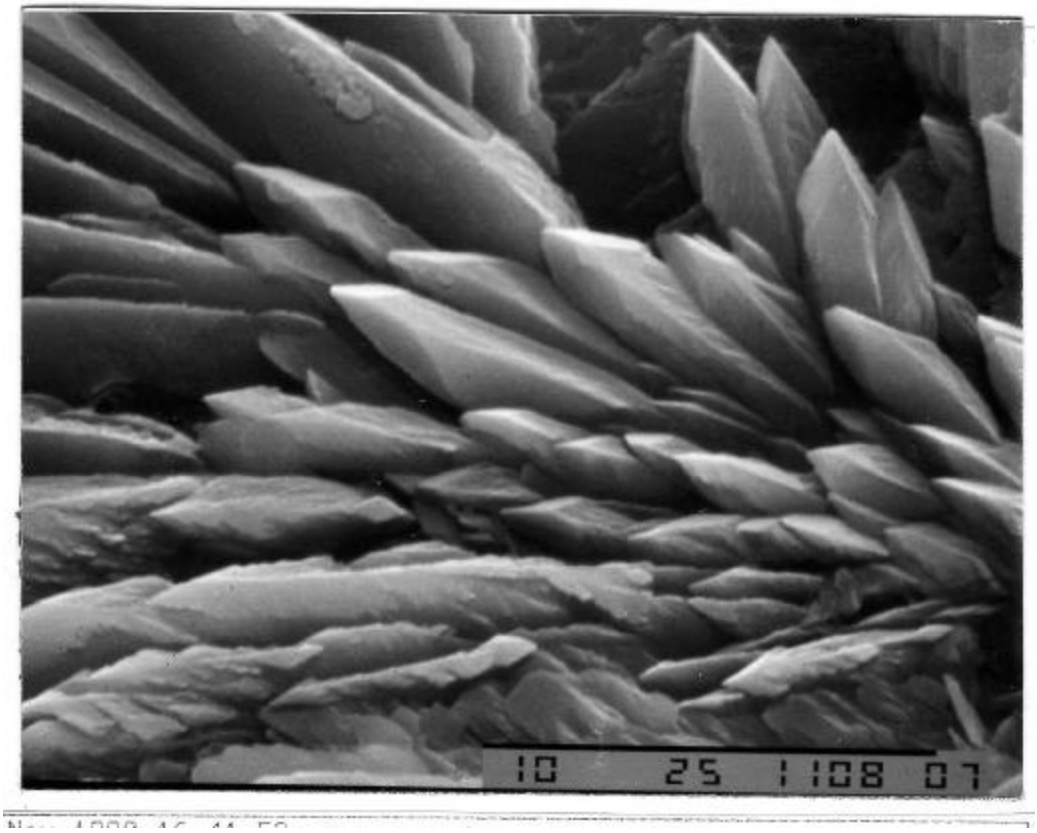

Figure 4. ANALYSISI OF SAMPLE 1M-244 IN AREA 1 SHOWN IN FIG. 3.

a) Scanning electron micrograph of crystals in area 1 on Fig.

b) EDS spectra collected from the crystals shown in Fig. 4a.

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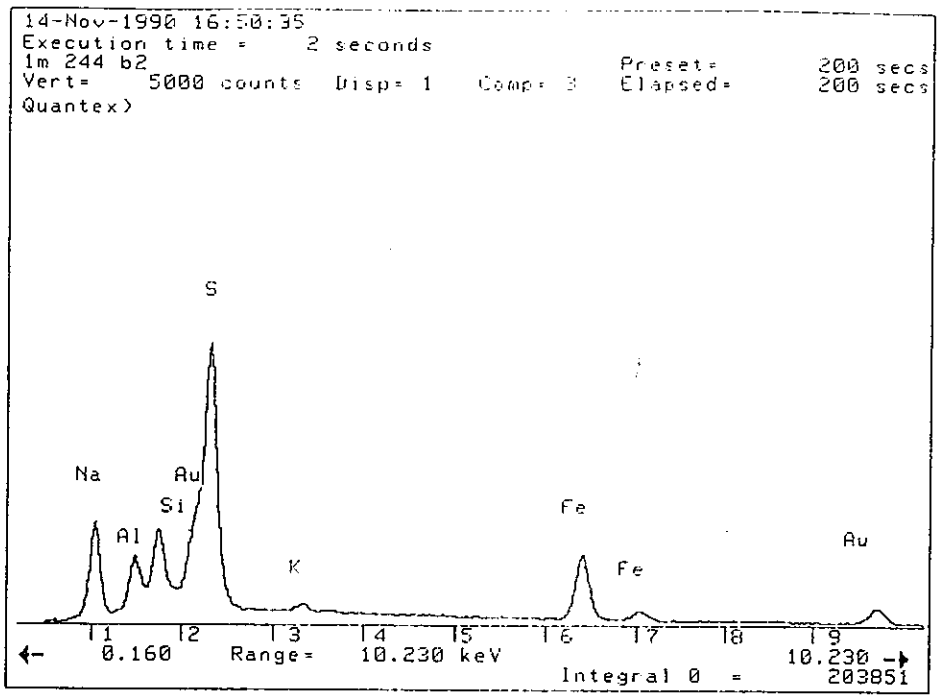

FIGURE 5. ENERGY DISPERSIVE SPECTRA COLLECTED FROM A GROUP OF CRYSTALS SIMILIAR TO ONE SHOWN IN FIG. 4a.

The Integrity Testing Laboratory
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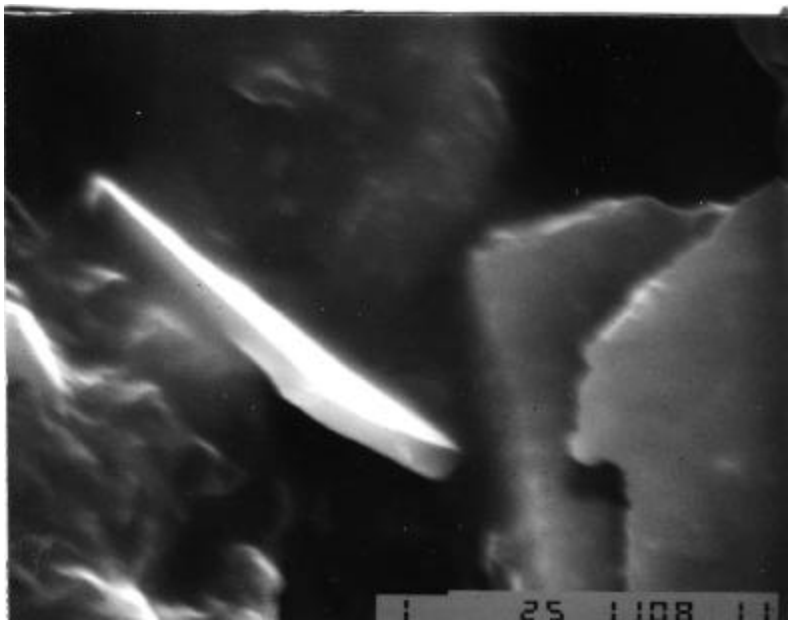
a)



b)

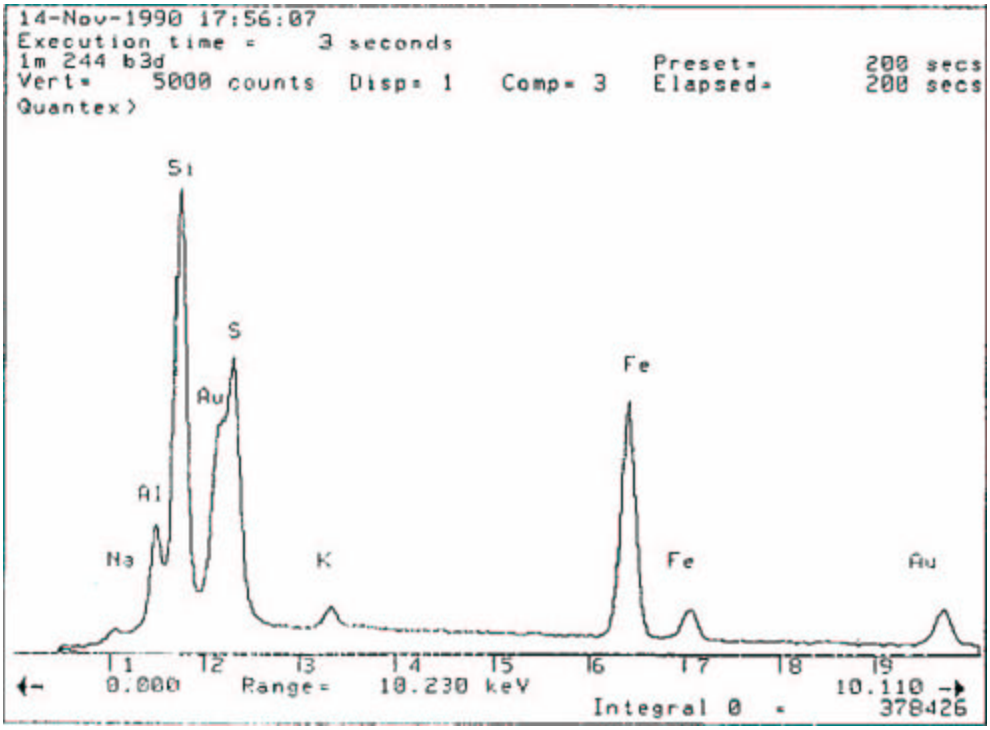


Figure 6 ANALYSISI OF SAMPLE 1M-244 IN AREA 2SHOWN IN FIG. 3.

a) Scanning electron micrograph of a flat crystal in area 2 on Fig. 3.

b) EDS spectra collected from the crystals shown in Fig. 6a.

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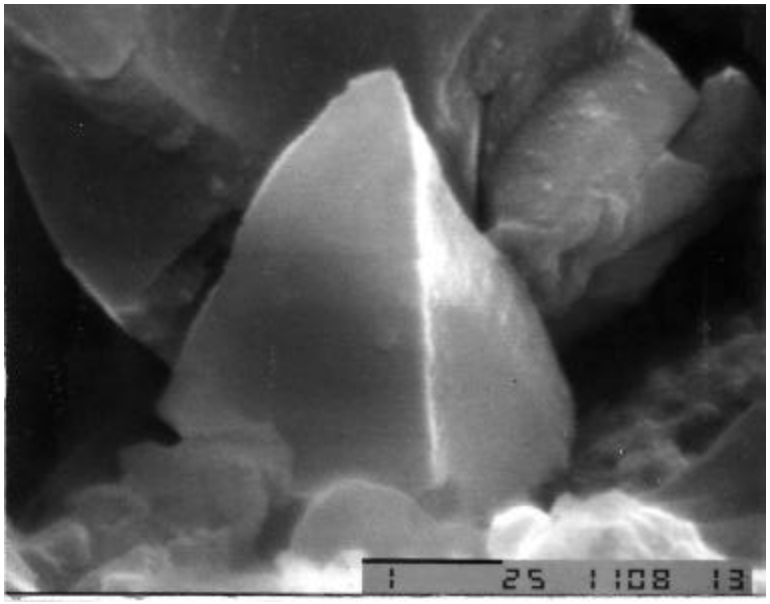
a)



b)

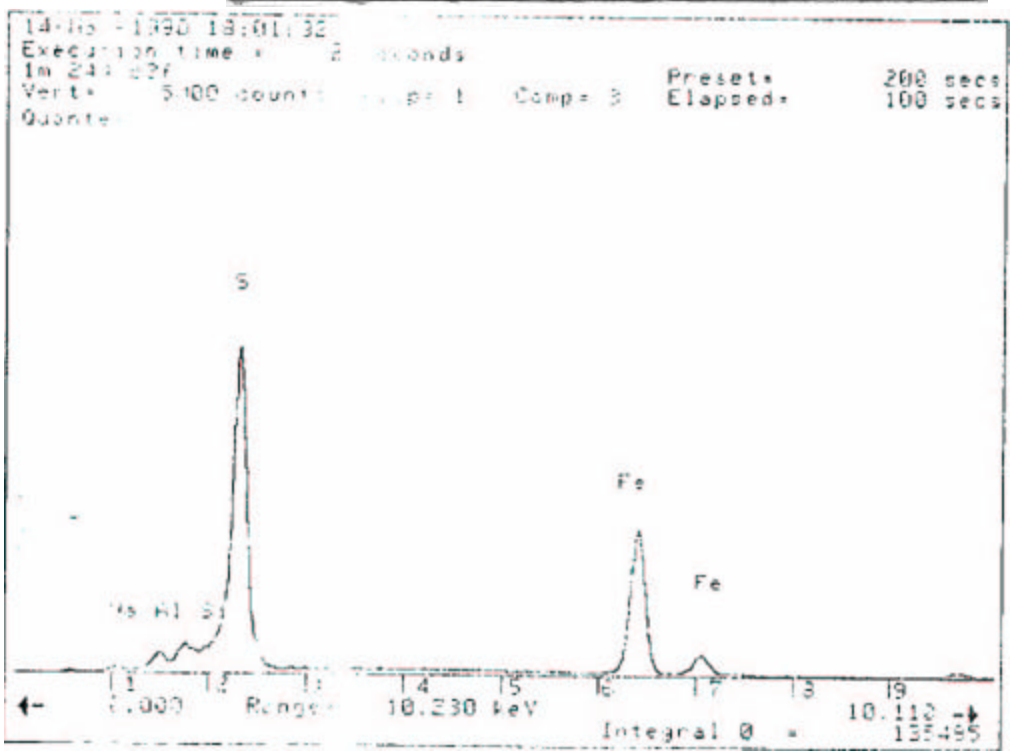


Figure 7 ANALYSISI OF SAMPLE 1M-244 IN AREA 3 SHOWN IN FIG. 3.
a) Scanning electron micrograph of a crystal found in area 3 on Fig. 3.
b) EDS spectra collected from the crystals shown in Fig. 7a.

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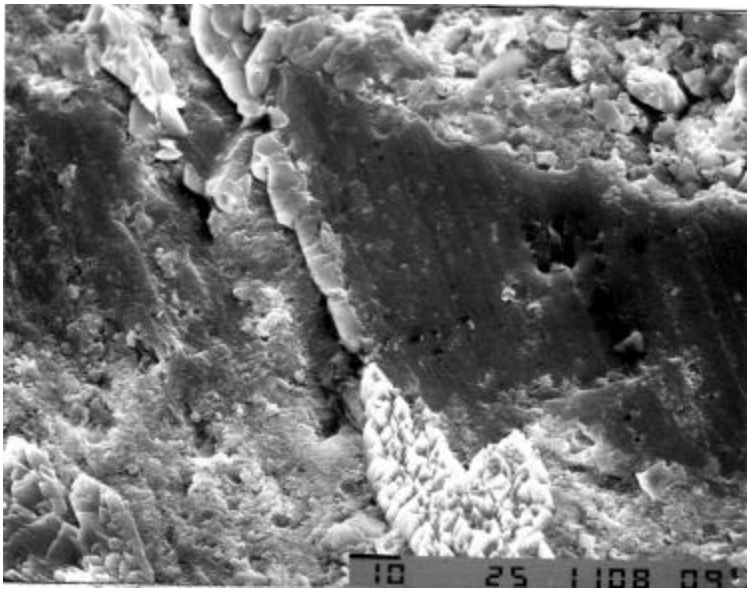
a)



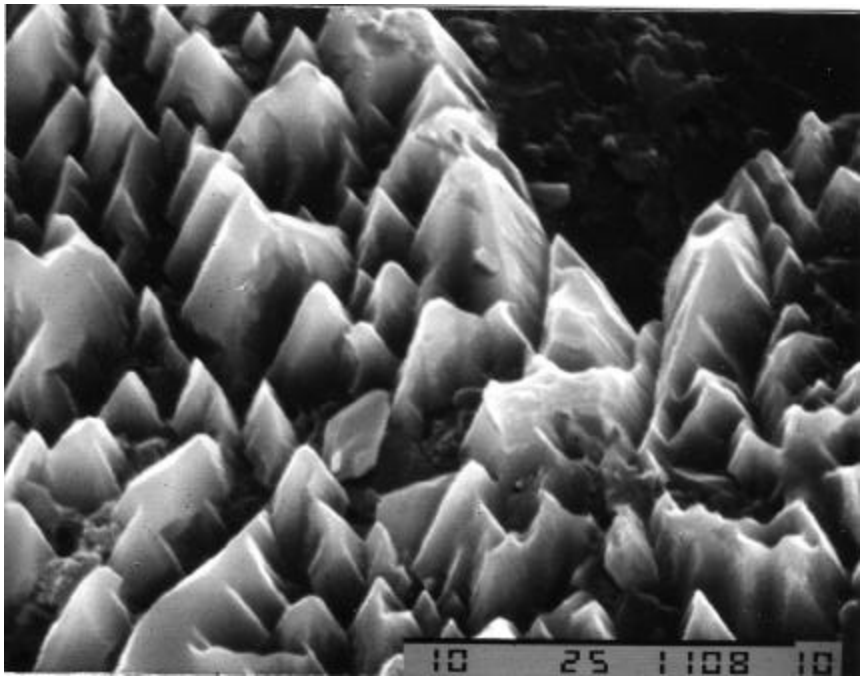


Figure 8 ANALYSISI OF SAMPLE 1M-244 IN AREA 5 SHOWN IN FIG. 3.
a) Scanning electron micrograph of a conglomerate of crystals found in area 5 on Fig. 3.

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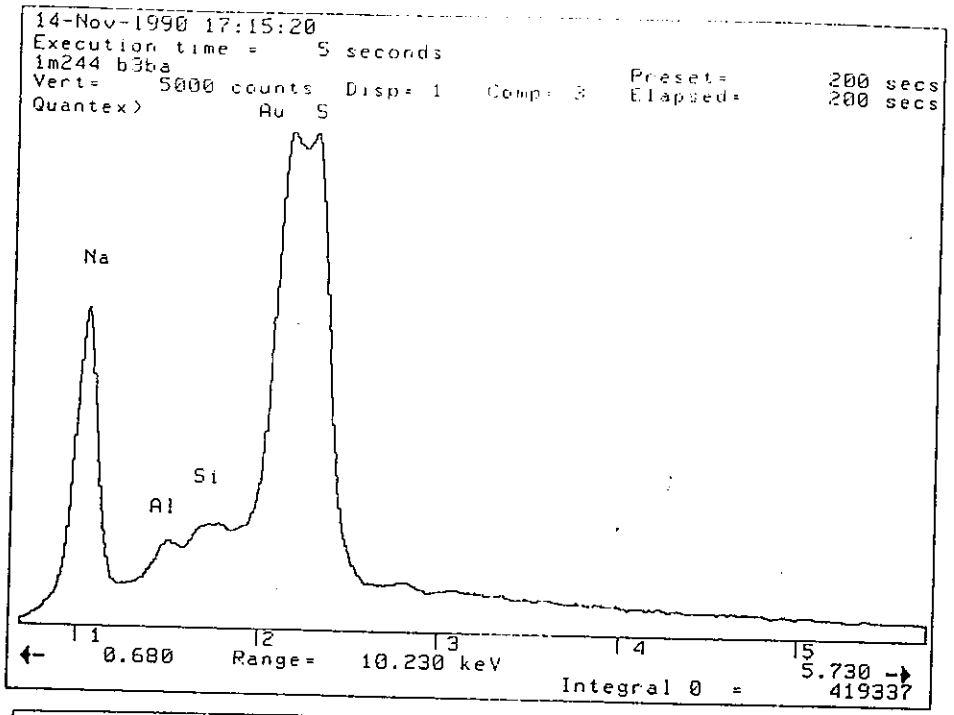
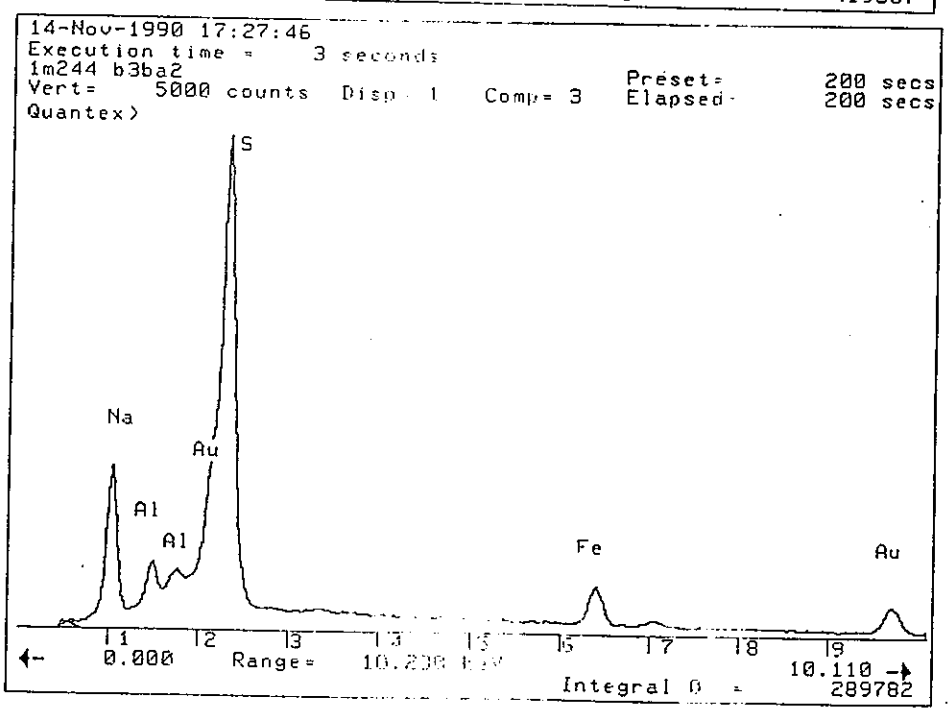
b)



c)



b) EDS spectra collected at 10 keV from a crystal shown in Fig.8a.

c) EDS spectra collected at 25 keV from the same crystal shown in Fig.8a.

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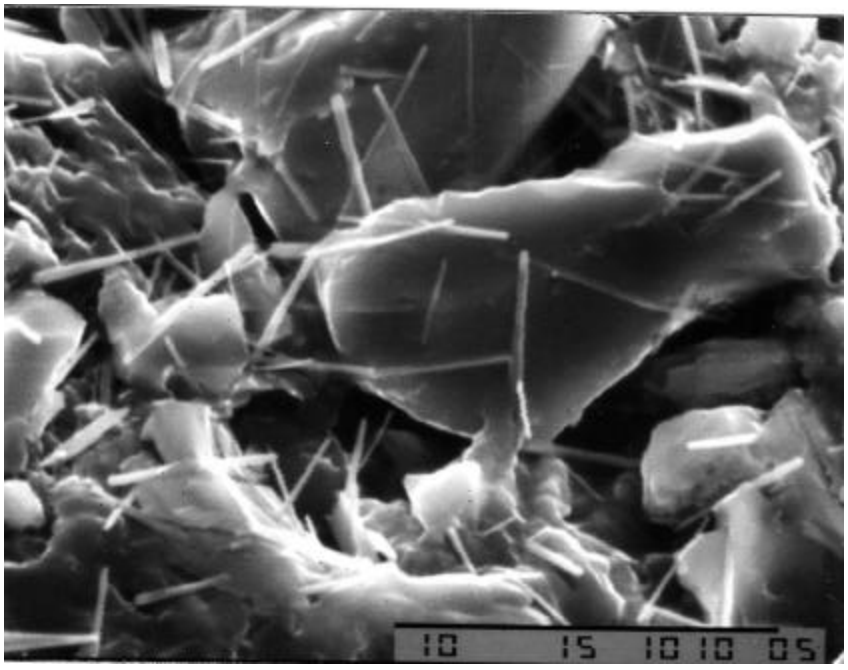
a)



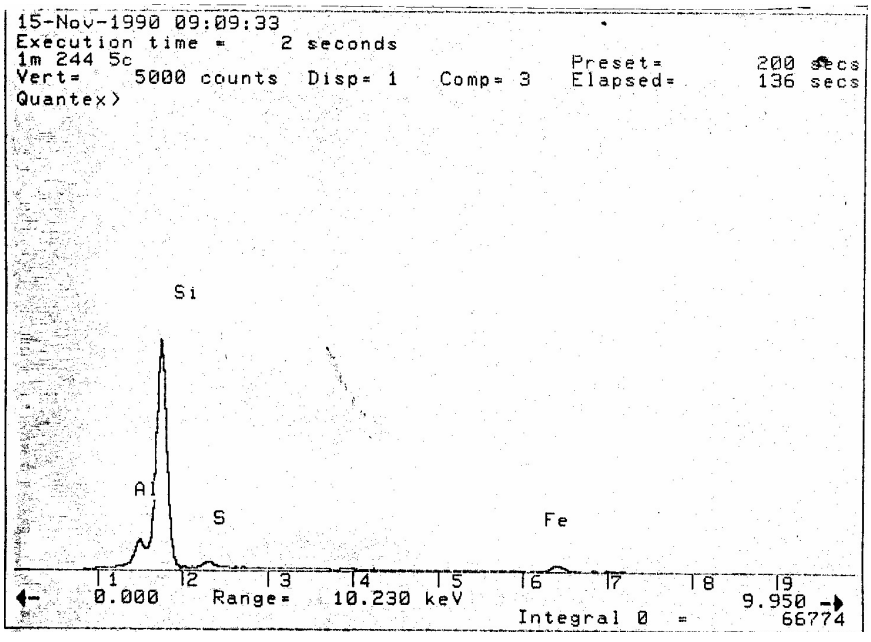


Figure 9. ANALYSISI OF SAMPLE 1M-244 IN AREA 5 SHOWN IN FIG. 1.

a) Scanning electron micrograph of a conglomerate of crystals found in area 5 on Fig. 1.

b) EDS spectra collected at 15 keV from a needle like crystal seen in Fig. 9a.

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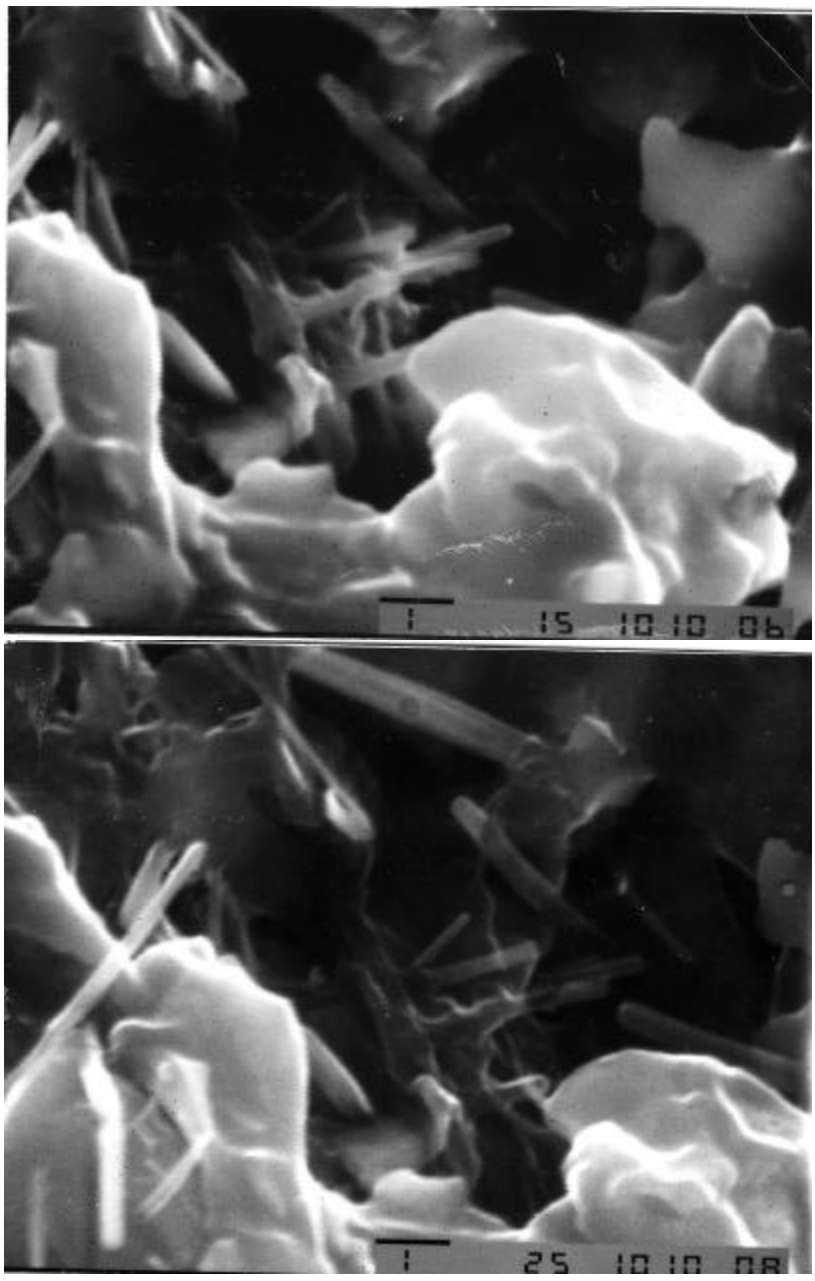

Figure 10. ANALYSISI OF SAMPLE 1M-244 IN AREA 5 SHOWN IN FIG. 1.
a) Scanning electron micrograph of a conglomerate of crystals found in area 5 on Fig. 1.

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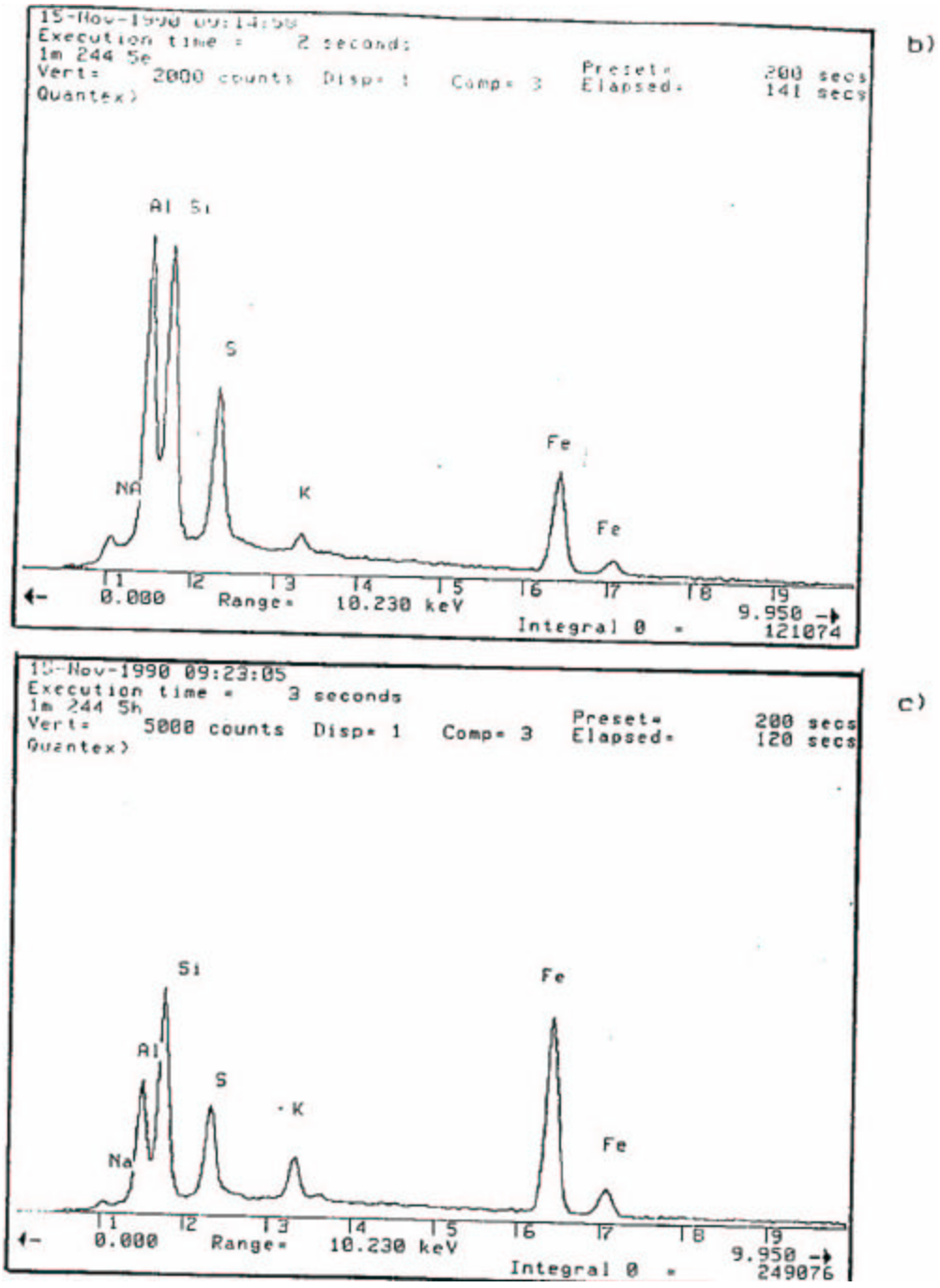

b) EDS spectra collected at 15 keV from a nodule seen in the centre of Fig. 10 (a and b).

c) EDS spctra collected at 25 keV from the same place as in Fig. 10b.

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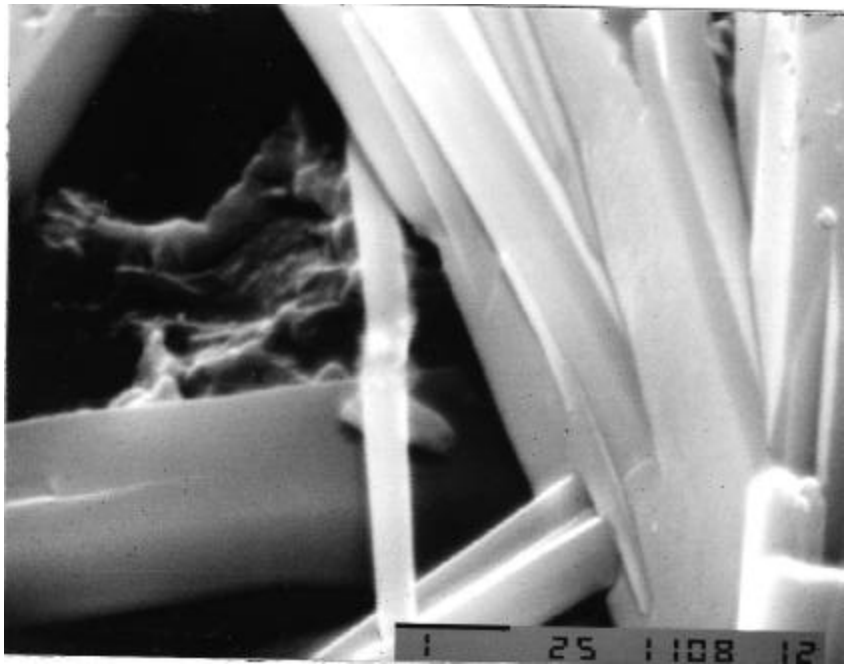
a)



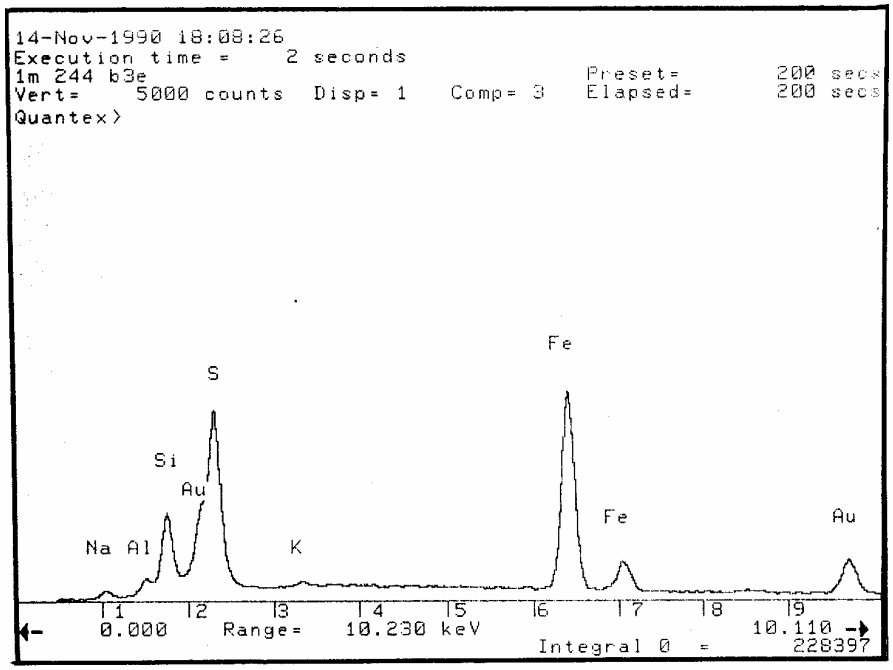


Figure 11. ANALYSISI OF SAMPLE 1M-244

a) Scanning electron micrograph of a conglomerate of crystals.

b) EDS spctra collected from the white, needle-like crystal seen in the centre of Fig. 11a.

SRMPLE M27-3

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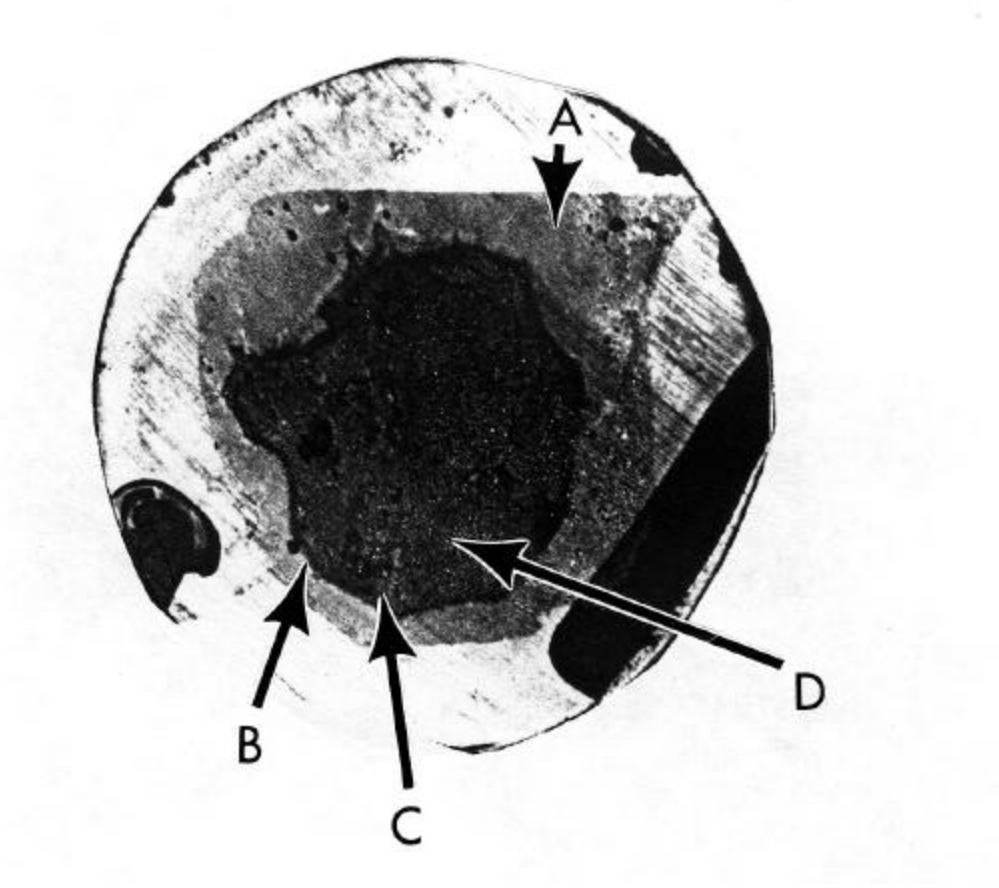

Figure 1. SCHEMATIC VIEW OF THE CROSS-SECTIONED SAMPLE M27-3. Arrow indicate areas analyzed and discussed in the text.

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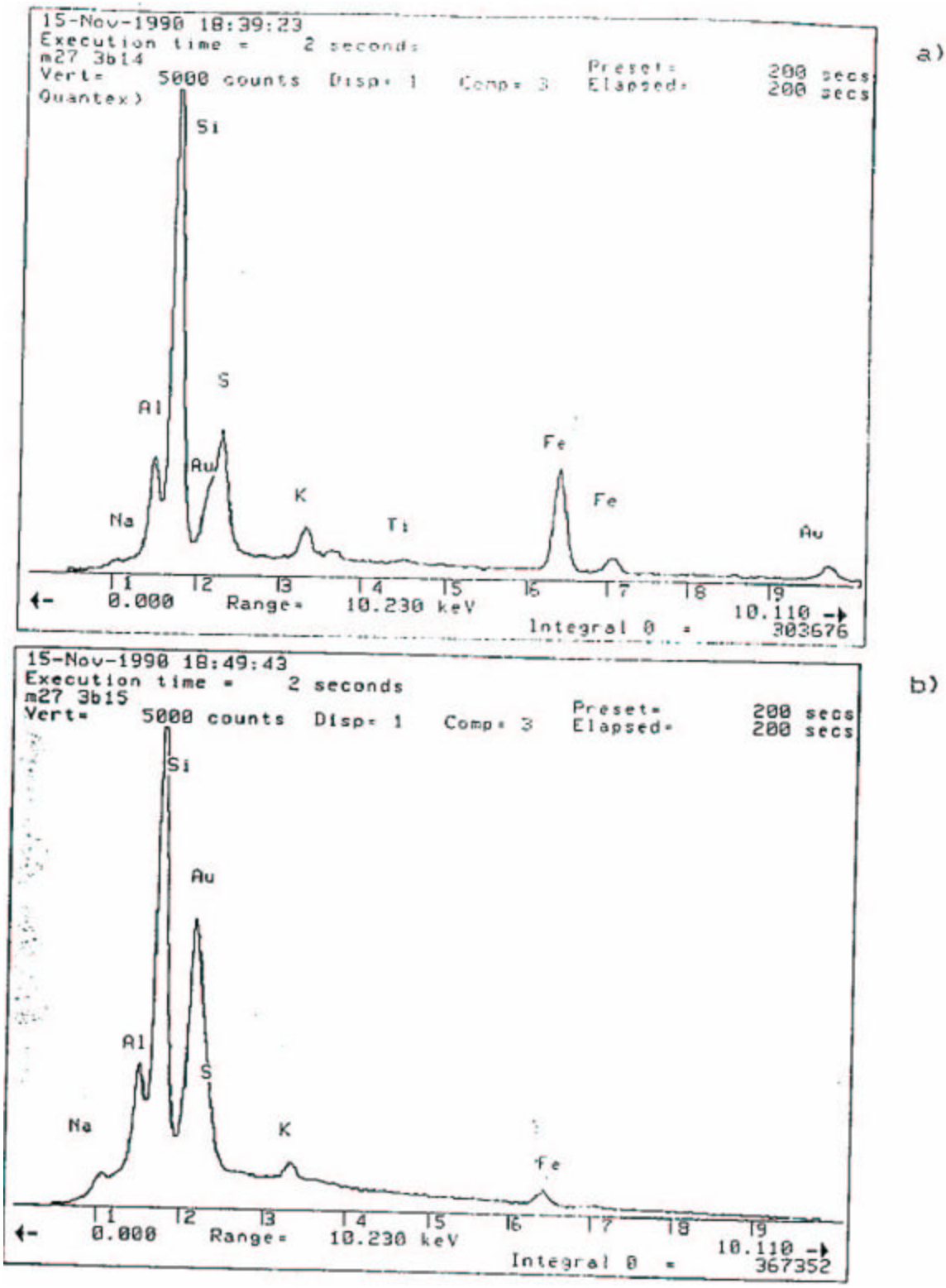

FIGURE 2. Typical EDS spectra collected from the deposit.
a) EDS spectra collected at 25 kV.
b) EDS spectra collected at 10 kV.

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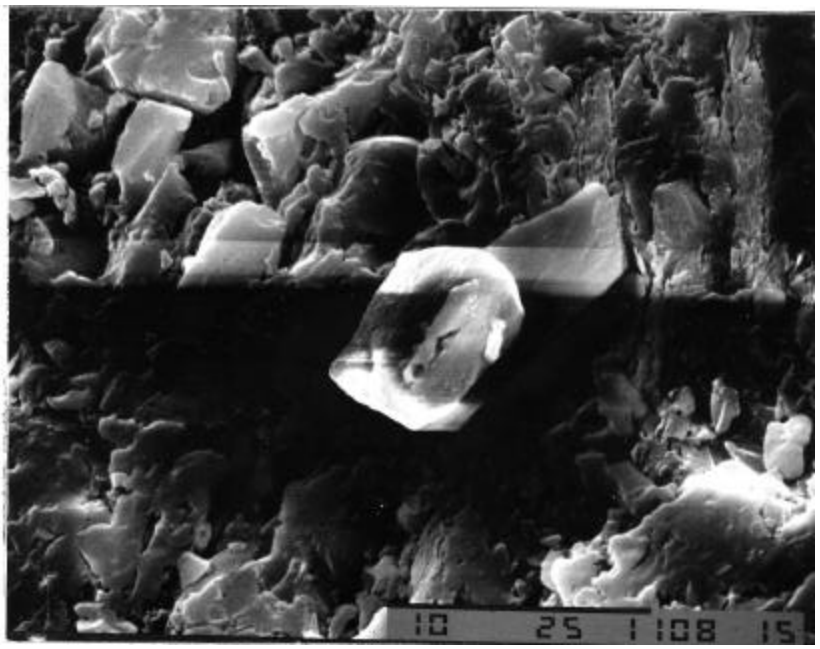
a)



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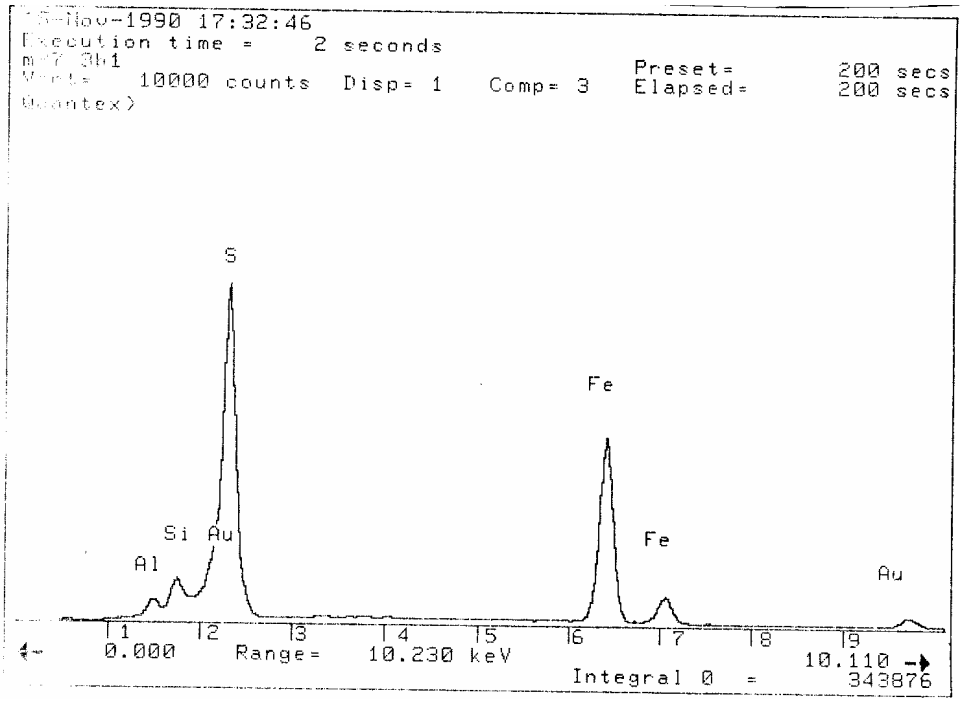

Figure 3. ANALYSISI OF AREA A ON FIG. 1.

a) Scanning electron micrograph of a particle found in area A on Fig. 1.
b) EDS spectra of the particle shown in Fig. 3a.

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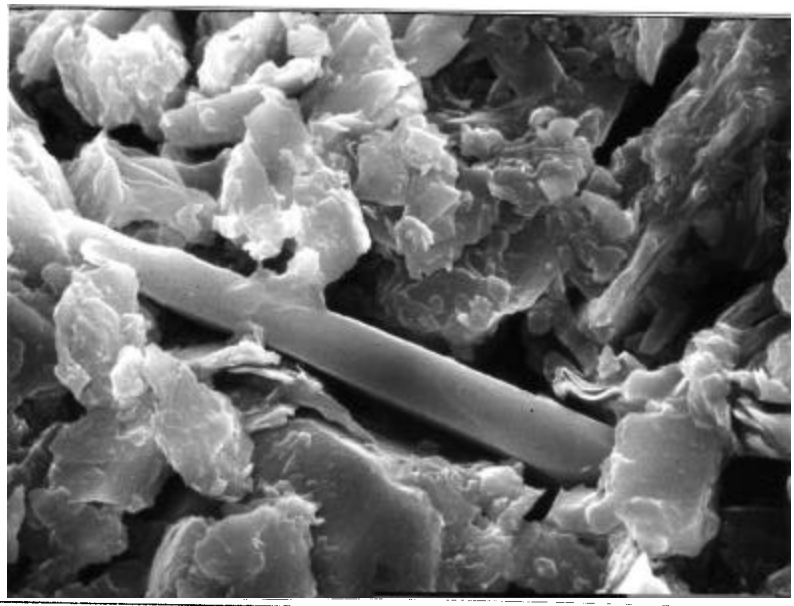
a)



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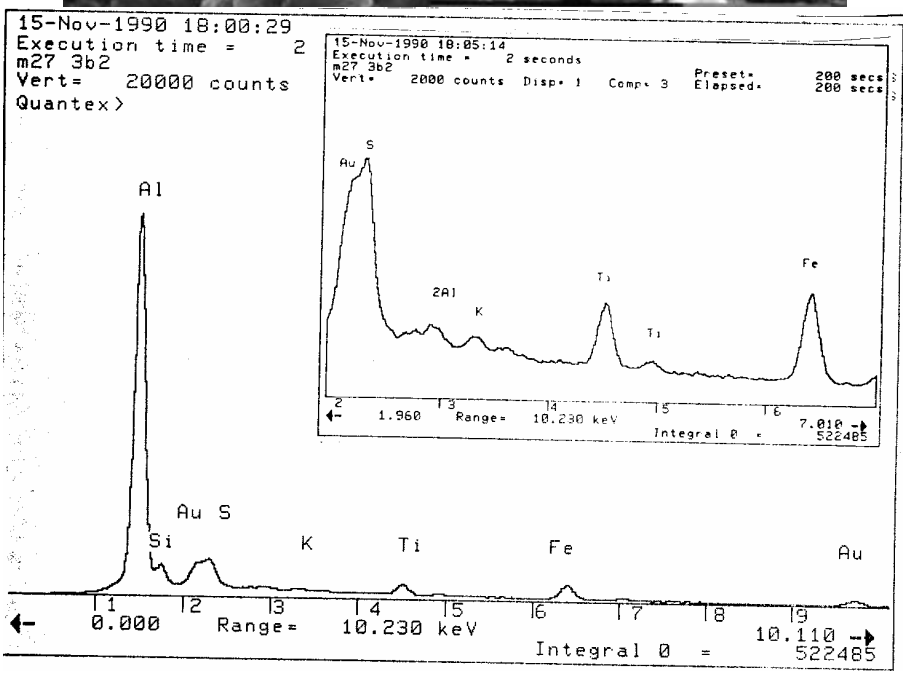

Figure 4. ANALYSISI OF AREA B ON FIG. 1.

a) Scanning electron micrograph of an elongated particle found in area B on Fig. 1.

b) EDS spectra of the elongatedparticle shown in Fig. 4a.
The insert shows in more details the energy range 2-6.5 keV.

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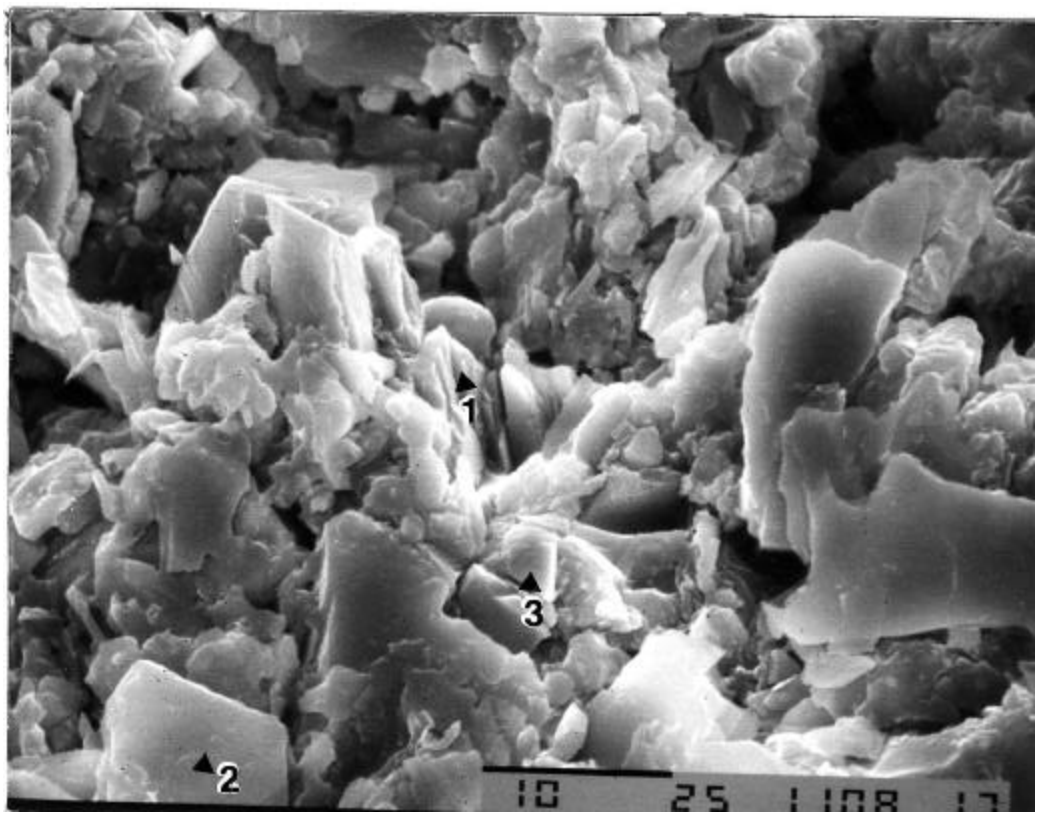

Figure 5. ANALYSISI OF AREA C ON FIG. 1.

a) Scanning electron micrograph of a region in area C.
Particles analyzed by EDS are marked with numbers 1-3.

b) EDS spectra of particle #1 shown in Fig. 5a.
The table below represents the results of semi-quantitative standartless analysis of the spectra.

c) EDS spectra of particle #2 shown in Fig. 5a.
The table below represents the results of semi-quantitative standartless analysis of the spectra.

Note: Particle #3 shown in Fig. 5a. exhibited a spectra characteristic of FeS_2.

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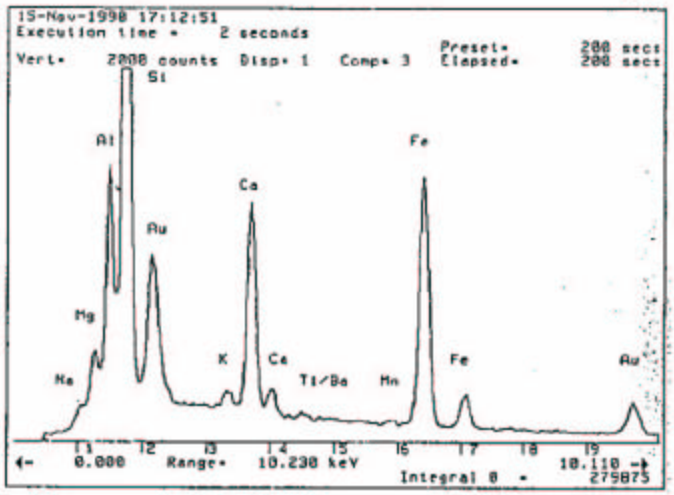
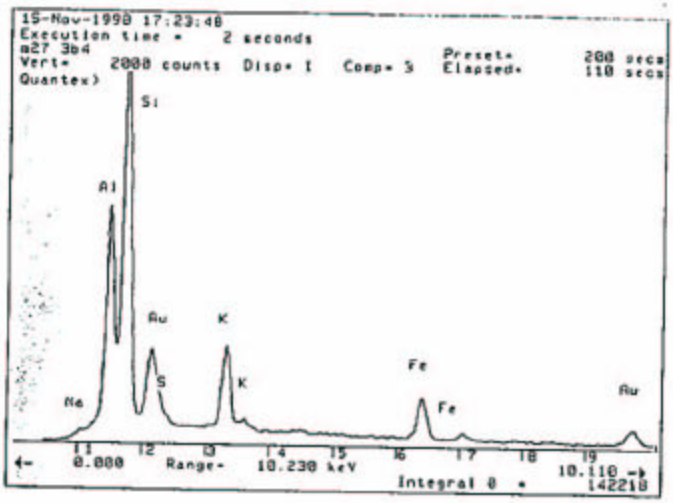
b)



c)



ELEMENT & LINE	WEIGHT PERCENT	ATOMIC PERCENT
Na KA	0.00	0.00
Mg KA	4.22	5.76
Al KA	15.72	19.33
Si KA	39.70	46.89
S KA	3.04	3.14
K KA	0.97	0.82
Ca KA	10.48	8.68
Fe KA	25.87	15.37

ELEMENT & LINE	WEIGHT PERCENT	ATOMIC PERCENT
Al KA	23.58	26.53
Si KA	51.58	55.77
S KA	4.25	4.03
K KA	10.53	8.18
Ti KA	0.22	0.14
Fe KA	9.84	5.35

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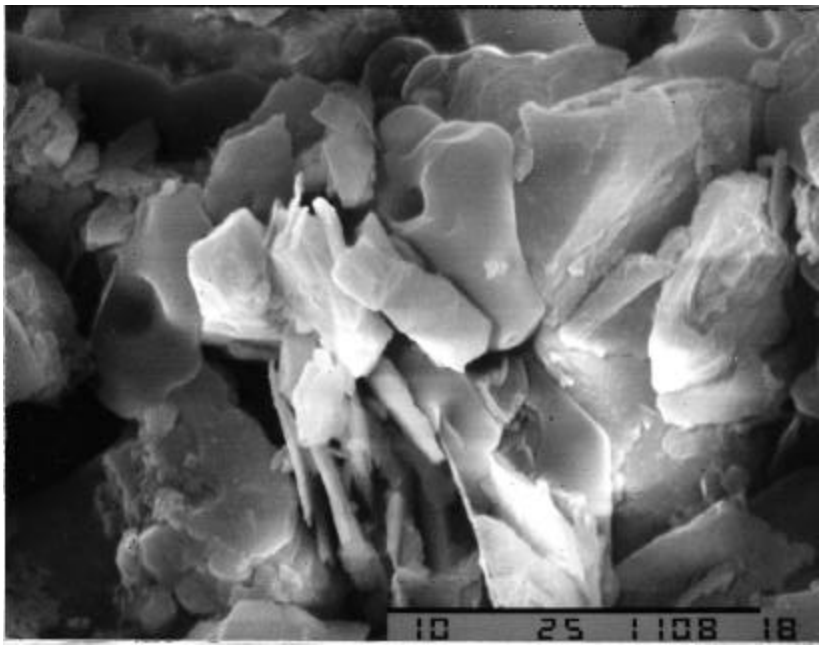
a)



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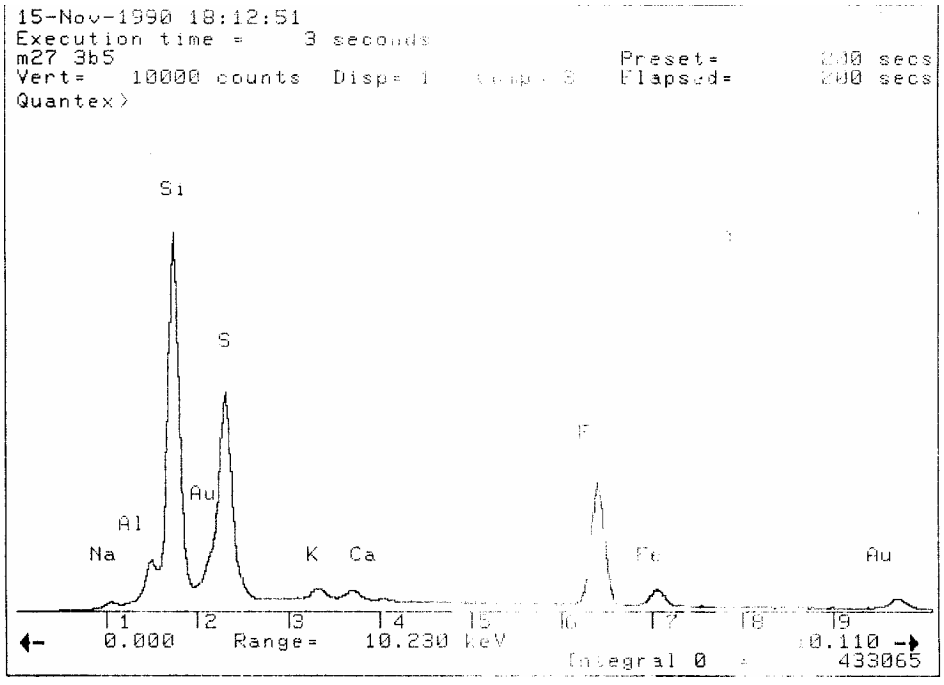

FIGURE 6. ANALYSISI OF AREA D ON FIG. 1.

a) Scanning electron micrograph of a region in area D.

b) EDS spectra o f a conglomerate of particles seen in the centre of Fig. 6a.

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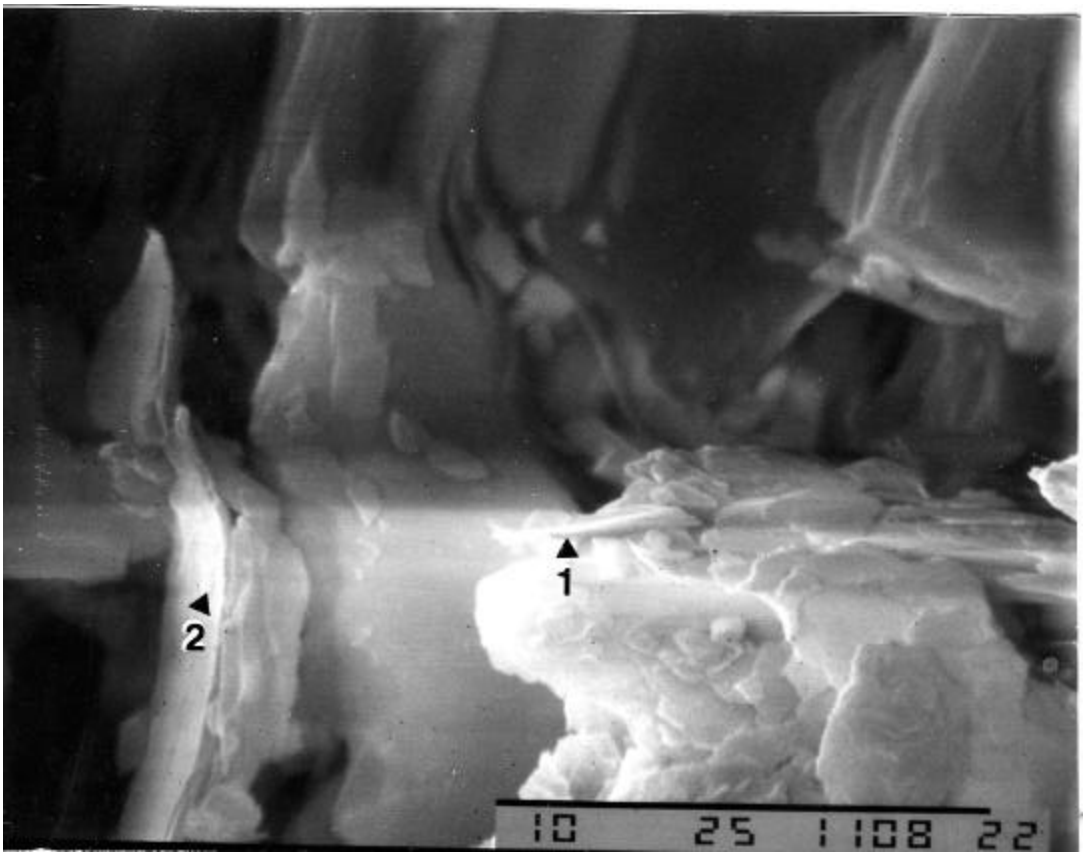

FIGURE 6. ANALYSISI OF AREA D ON FIG. 1.

Scanning electron micrograph of a region in area D on Fig. 1.

Particles analyzed by EDS are marked with numbers 1 and 2.

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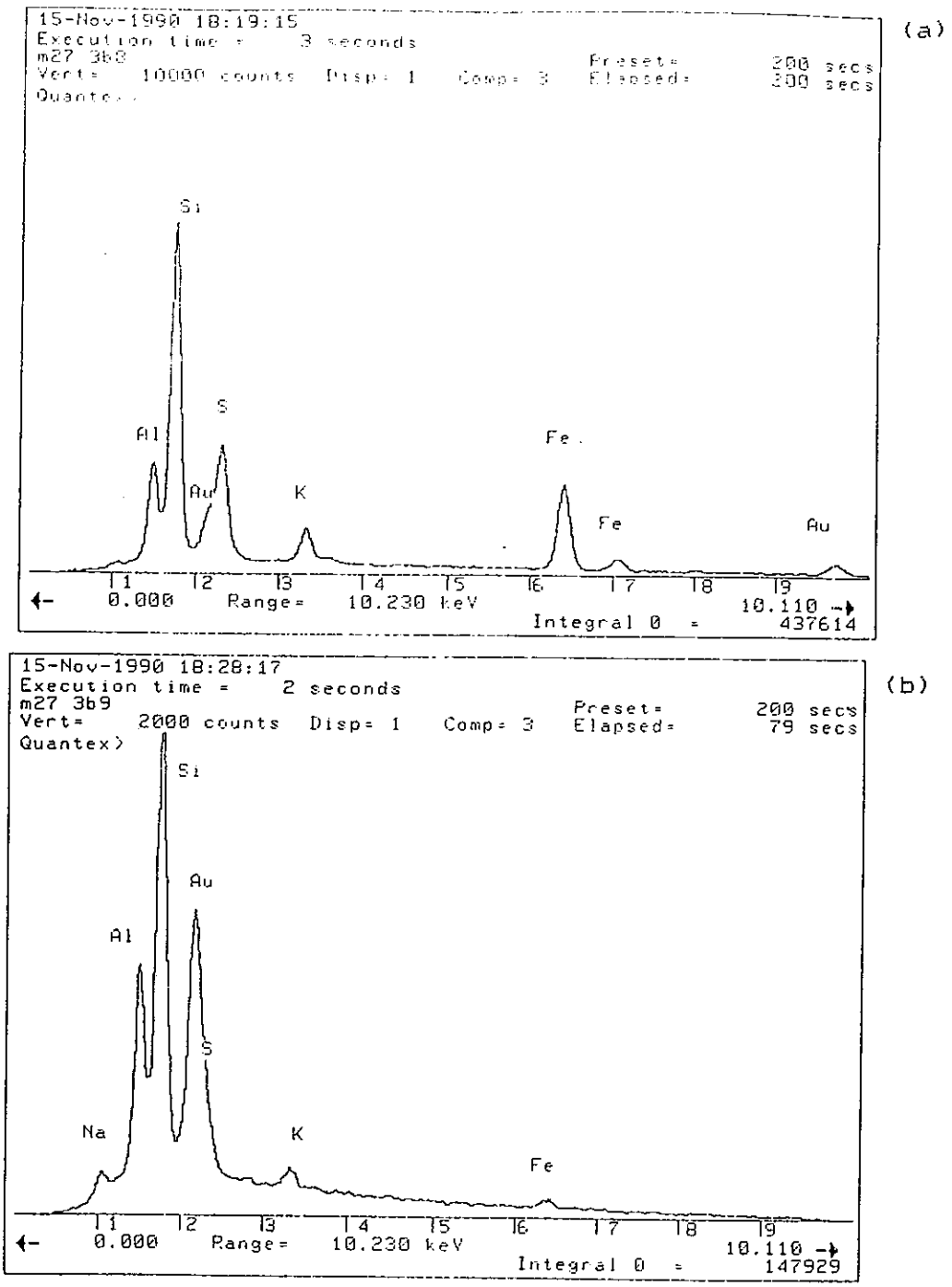

FIGURE 8. EDS SPECTRA OF PARTICLE #1 SHOWN IN FIG.7 COLLECTED AT 25 keV (a) AND 10 keV (b).

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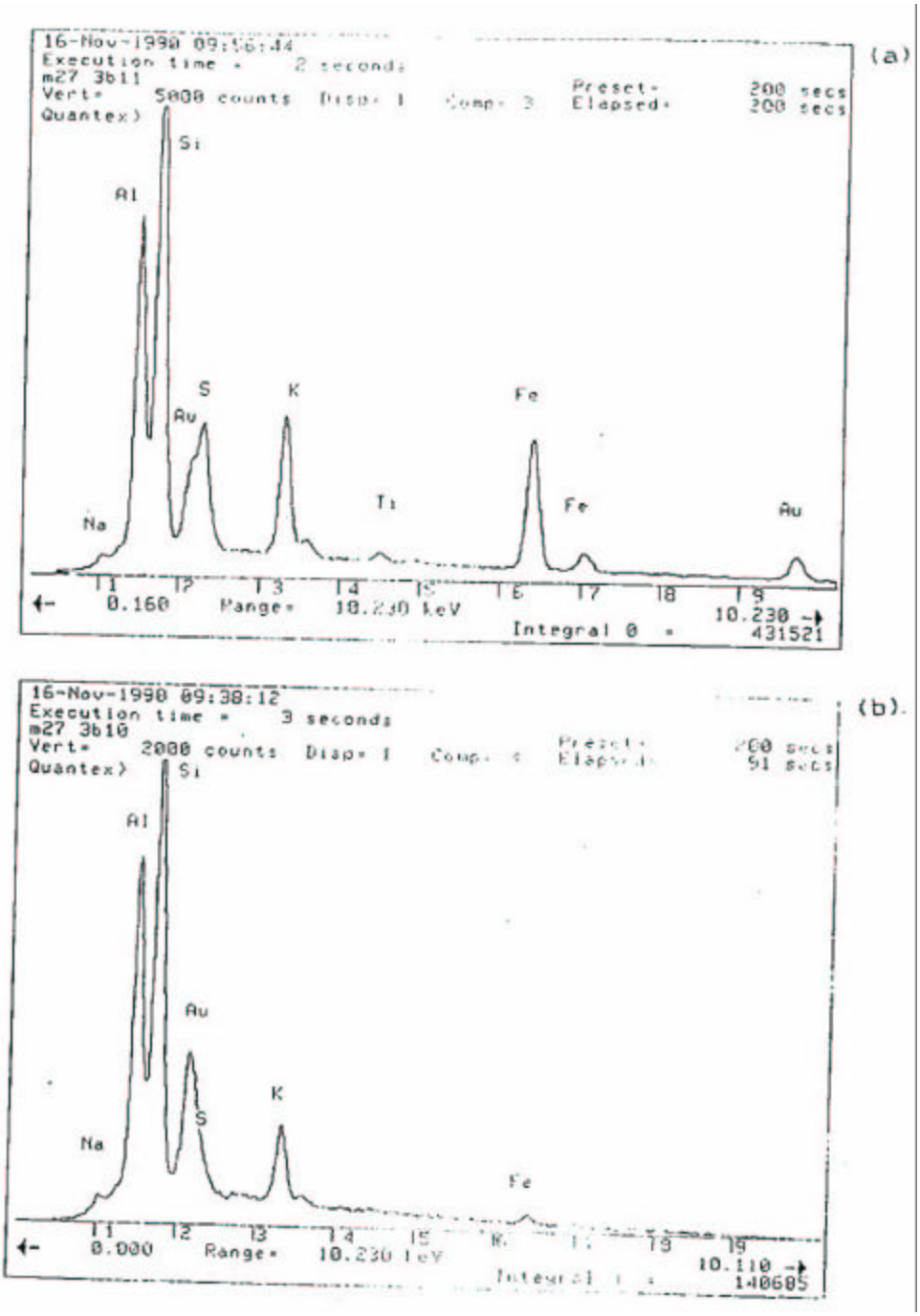

FIGURE 9. EDS spectra of particle #2 shown in Fig. 7 collected at 25 keV (a) and 10 keV (b)

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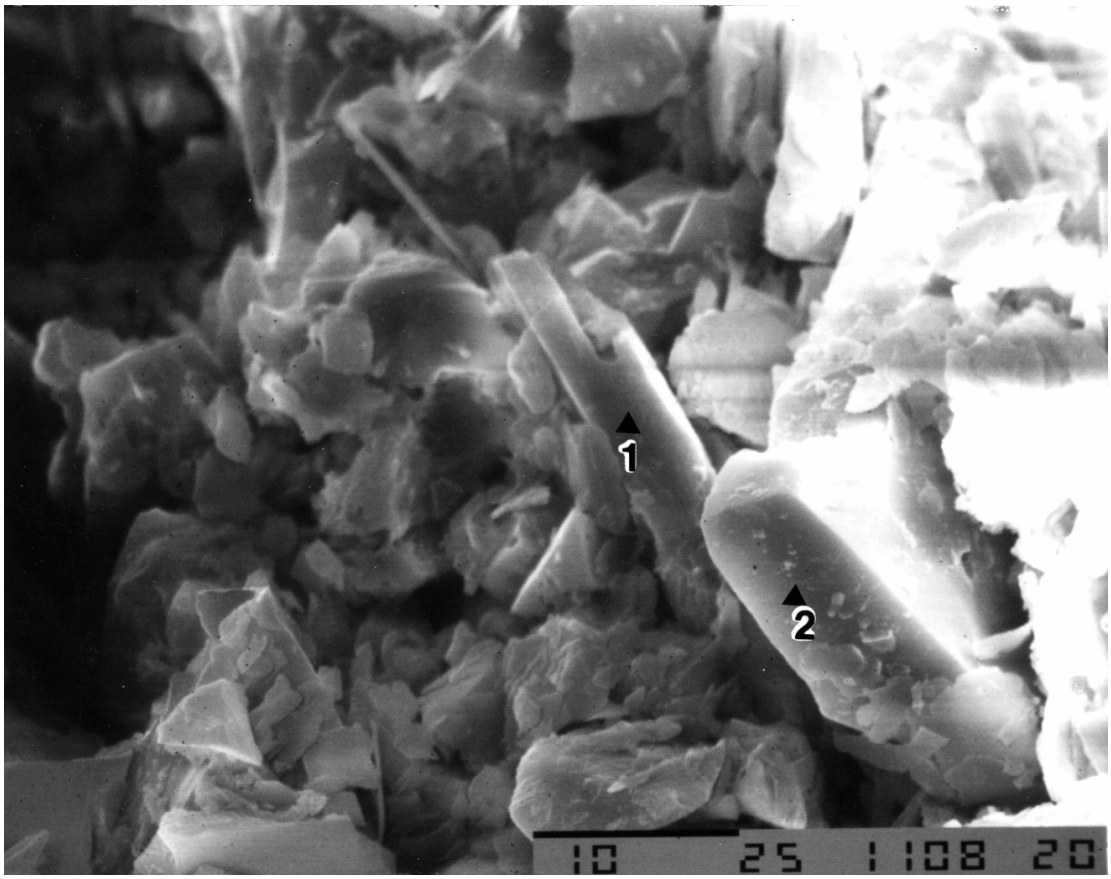

FIGURE 10. Scanning electron microscopy of an area on the sample M27-3.

Numbers indicate particles analyzed with EDS.

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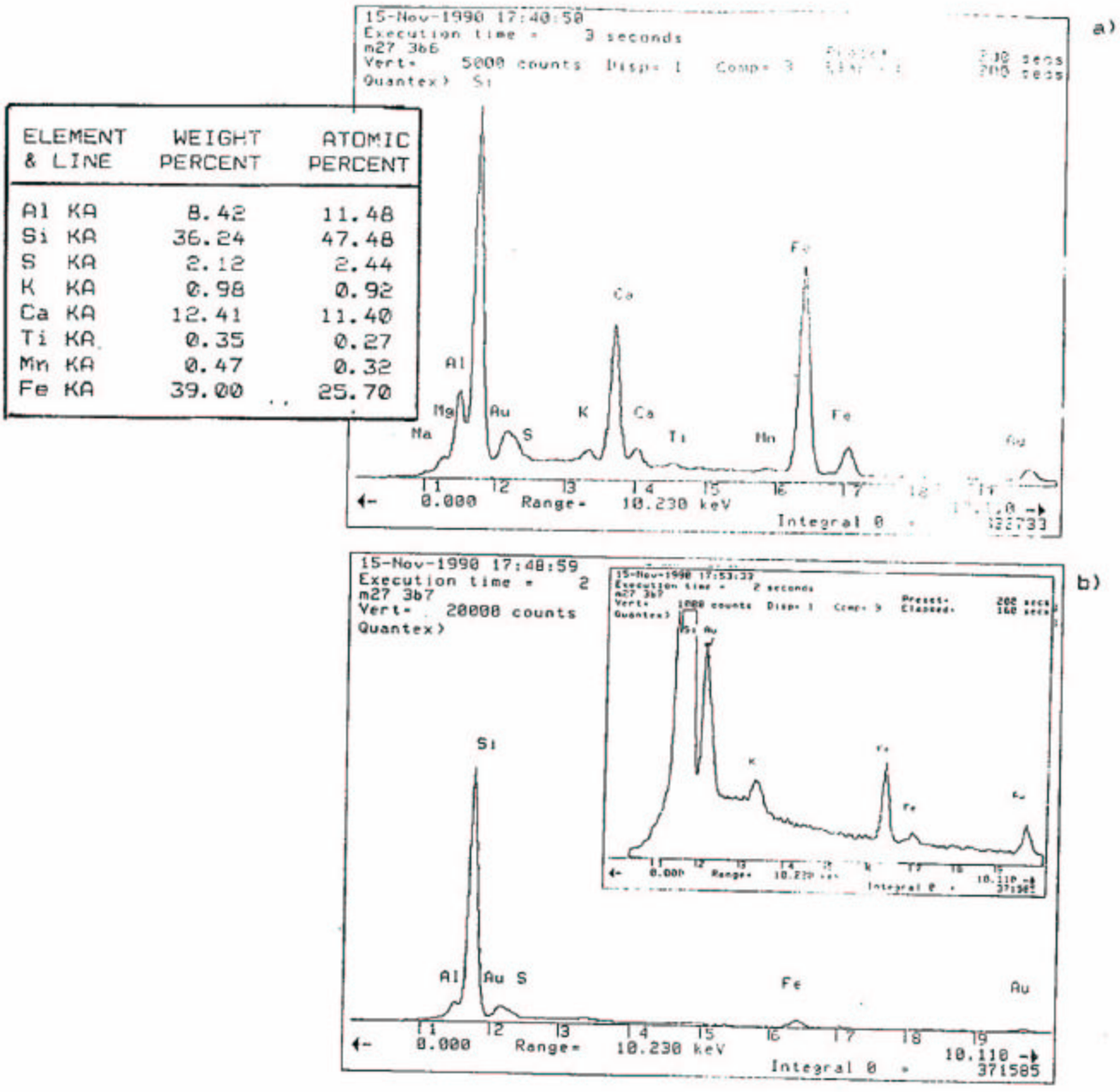

ELEMENT & LINE	WEIGHT PERCENT	ATOMIC PERCENT
Al KA	8.42	11.48
Si KA	36.24	47.48
S KA	2.12	2.44
K KA	0.98	0.92
Ca KA	12.41	11.40
Ti KA	0.35	0.27
Mn KA	0.47	0.32
Fe KA	39.00	25.70

FIGURE 11. EDS ANALYSIS OF PARTICLES SHOWN IN FIG.10.

a) EDS spectra collected from particle #1 in Fig.10. The table on the left represents the results of semi-quantitative standartless analysis of the spectra.

b) EDS spectra collected from particle #2 in Fig.10. The insert shows the same spectra on an enlarged vertical scale.

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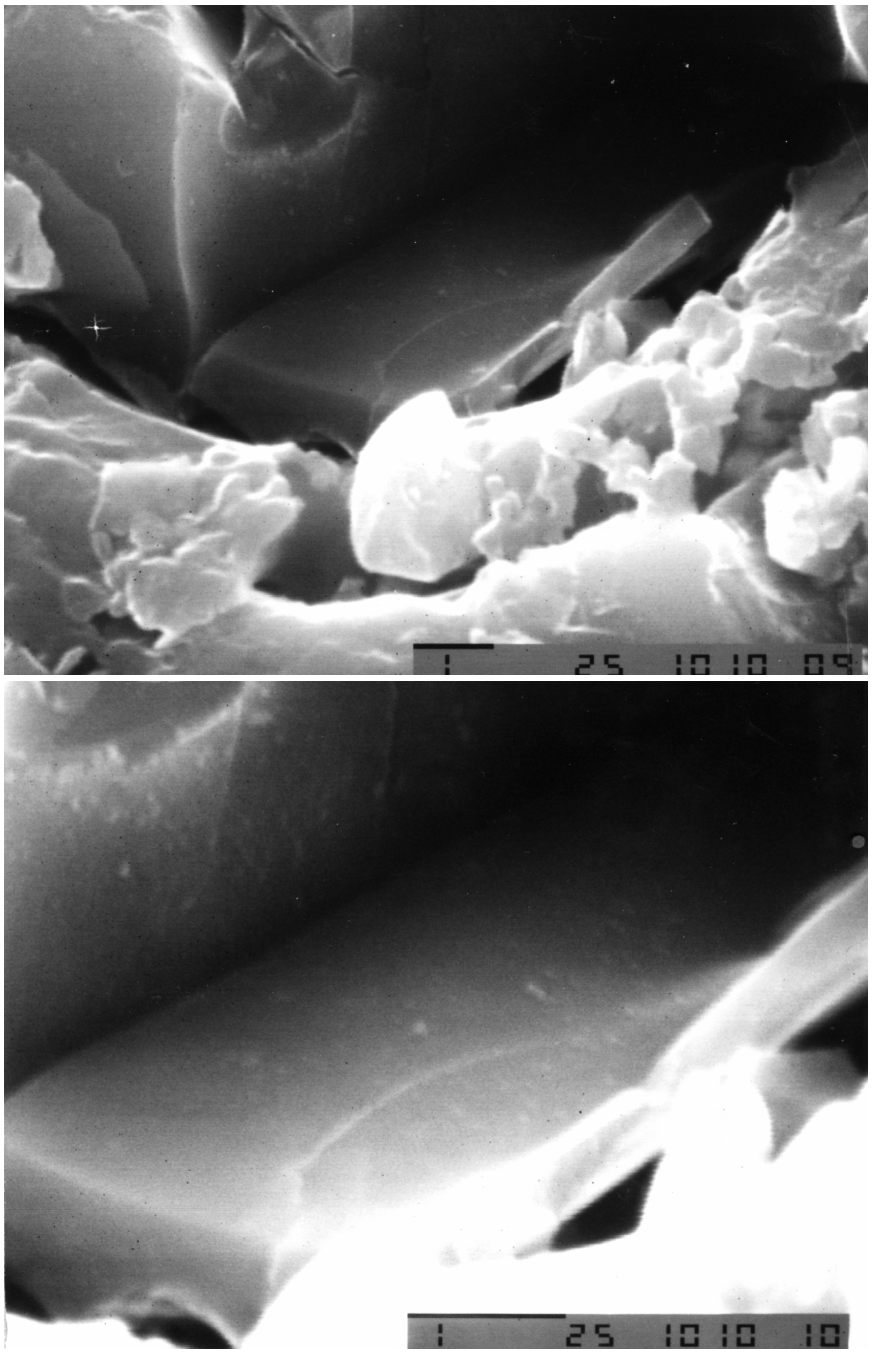

FIGURE 12. Scanning electron microscopy of an area on the sample M27-3.

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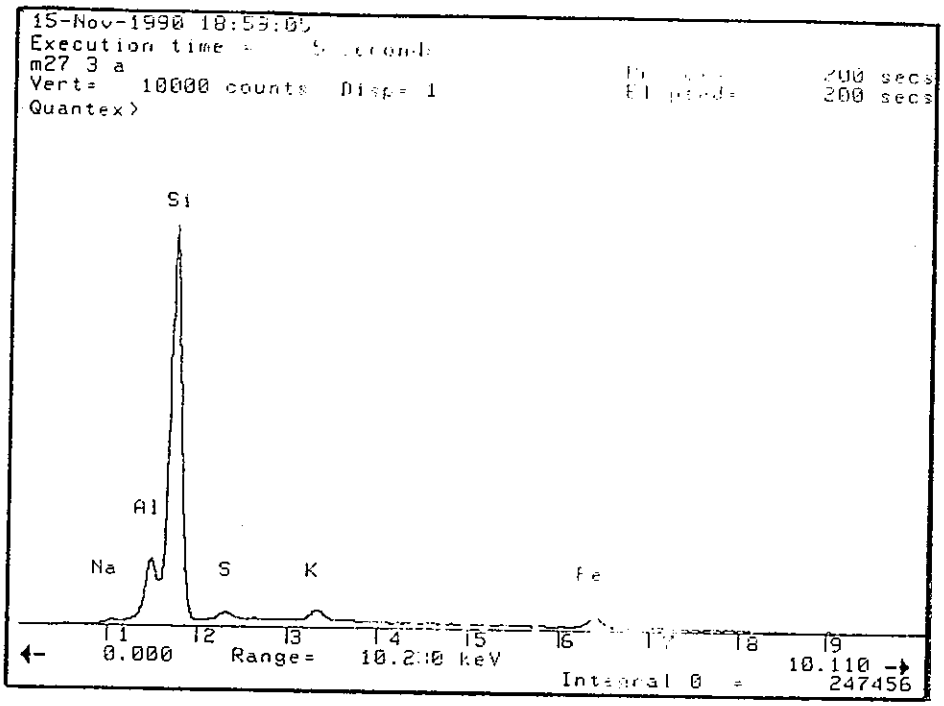

FIGURE 13. EDS ANALYSIS OF THE FLAT PARTICLE SHOWN IN FIG. 12.